

Article

Narrative Inquiry on the Teaching of STEM to Blind High School Students

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Abstract: This study aimed to elevate the experiences and voices of teachers who led the STEM informal education program summer series: National Federation of the Blind Engineering Quotient (NFB EQ). Through its integration with science, technology, engineering, and math (STEM), NFB EQ opened opportunities from 2013–2016 in Baltimore, Maryland, for 60 blind students (Grades 9–12) to learn about engineering. The purpose of this narrative inquiry study was to understand how teachers foster interest towards STEM among blind students. The participants were two sighted teachers, one blind teacher, one sighted teacher–researcher, and one sighted researcher participant. We collected data in the form of field notes, semi-structured interviews, personal narratives, collective narratives, a focus group discussion, and teaching artifacts. We engaged in conversation analysis and used MAXQDA 12 software for data analysis. Guided by the principles of community of practices and universal design for learning, our results identified the importance of teacher awareness and positionalities in guiding blind students’ inclusion and identity in the STEM classroom. Findings also suggest teachers are in a unique position to allow or prevent inclusive opportunities from occurring in their classrooms.

Keywords: informal STEM learning; high school; special education; community of practice; universal design for learning

1. Introduction

In 2009, Warren–Peace analyzed the outcomes and predictors of employment between blind clients and other “disabled” clients (“disability” under Social Security is based on the physical inability to work). Results indicated that compared to 19 other “disability” types, blind people accounted for 43.6% of the total non-competitive employment (e.g., homemaker, unpaid family worker) in the United States [1]. Similarly, a 2015 study [2] found that there has not been a change in these employment statistics for the blind. Based on the findings from both studies, educational attainment significantly factors into employment of the blind; those who have a graduate-level education are employed at twice the rate of those with only a high school diploma [1,2]. While the blind population with a clinically diagnosed visual disability consists of over seven million individuals in the United States, blind people represent less than 5% of all the science, technology, engineering, and mathematics (STEM) workforce [3]. This presents a missed opportunity to increase the representation of many underrepresented populations (including those with disabilities) in areas such as STEM. Furthermore, this prognostic may leave many secondary-level blind students feeling discouraged from participating in such careers because of a “perceived lack of teacher support” [4] (p. 196), perceived lack of parental/legal guardian support [4], or limited career outlook in these fields [4,5].

Considering these statistics, the purpose of this narrative inquiry was to explore how teachers can foster interest towards science, technology, engineering, and mathematics (STEM) careers among

blind students. This study used the narratives of blind students' teachers (both trained and not trained in blind student education) to understand ways in which secondary education teachers can foster interest in STEM among their blind youth. Specifically, we collected the narratives, identities, and positionalities of a group of teachers, teacher/researcher, and researchers who are directly and indirectly involved with the STEM informal education program series: National Federation of the Blind Engineering Quotient (NFB EQ). NFB EQ was a series of summer STEM informal education week-long residency programs for blind high school students (Grades 9–12). This work was funded by the National Science Foundation (NSF) from 2013–2016 and took place at the Jernigan Institute in the NFB headquarters in Baltimore, Maryland. We decided to collect the voices of the teachers rather than the blind youth as NFB expressed to us their concern on how typically, blind youth are often recruited for educational research, and the young participants have little to no control over the outcomes of the study. In a conscious effort to respect the wishes of NFB, we sought their permission to study the teachers instead as we believe that the teachers may be uniquely positioned to change the landscape of the learning environment and create more inclusive secondary education spaces for the blind youth.

This narrative inquiry first positions the authors of this work as "sighted" individuals who may not fully understand the experiences of blind individuals; however, they have received some enlightenment from the stories of blind students' teachers and their lived experiences [6]. We understand that narrative is "meaning making through the shaping or ordering of experience" [7] (p. 430) and through the introspective reflection on researchers' positionalities and identities. It is through the shaping and ordering of the blind students' teachers' narratives about their three-year NFB EQ experience that we propose to *make meaning*. We explored the possibility that such meanings can significantly impact future instructional interventions for the benefit of blind students pursuing or interested in STEM education and careers.

We have learned about and now mirror the views that the National Federation of the Blind has about a blind individual, although we respect if an individual prefers to self-identify themselves differently. For the purpose of this manuscript, we propose that a blind individual "does not mean that one cannot see" [8] (p. 8). In the Idalis's interactions with blind individuals at NFB, we learned that many blind individuals have expressed a desire to be referred to as a "blind person" over other terms such as "visually impaired" or "low vision" [9]. Thus, when referring to blind individuals, we should consider the use of identity-first language instead of person-to-person first language (i.e., blind person versus a person who is blind) as this can be more authentic to blind people [8,9].

NFB has provided a working definition of blindness to help the general audience understand the notion that blindness is a characteristic treated as everything else and cannot be measured medically or physically but rather functionally [8]. In other words, benchmarks or traits defining "blindness" should also consider a blind person's pattern of daily living and the degree to which their everyday functions are altered (not substituted) [8]. Similarly, the authors believed that other forms of "disability" could be perceived in the same way; as such, the term "disabled" or similar forms of the word were bracketed in quotations to put into question the use of this term in education and research.

Unfortunately, misconceptions between blindness as a deficiency and a blind person's actual ability and functionality constrain the opportunities that many blind people have to equitable education and career paths. This is particularly prevalent in careers in STEM where "vision" is erroneously considered as a major information-gathering tool for a student to learn and acquire the needed skills for success in these fields. For example, the National Academies has reported that a fundamental skill that students need to acquire to be successful in STEM is spatial ability [10]. Spatial ability is a cognitive skill that requires an individual's understanding of space in order to mentally manipulate 3-D objects and environments to visualize an object, a geographical location, or the property of a given object [10–12]. For a blind student, "the spontaneous tendency to organize one's environment [. . .] requires more cognitive effort in view of the lack of visual information" [13] (p. 24). Researchers are only now beginning to understand the ways in which STEM skills that require visual information are being studied for blind youth [14]. To our understanding, no work has explored the instructional strategies

and challenges that teachers face when teaching these types of specialized STEM skills (particularly those that require visual information) to their blind youth in secondary education settings. Our work aims to begin to explore this gap in knowledge.

Our conceptual lenses guided us to explore how blind and sighted teachers' perceptions and expectations of blind students' knowledge and ability in STEM changed when teaching a week-long summer program where all students in the program were blind. In addition, we also explored if and how traditional instructional approaches for inclusive education (i.e., universal Design for learning or UDL) influence teachers' approach to instruction.

With this premise in mind, our research questions for this study included the following:

1. How do blind and sighted teachers' perceptions of teaching STEM to blind students change as a result of the NFB EQ experience and approach?
2. What strategies do teachers use to engage a classroom of blind students to STEM?

2. Theoretical Framework

We argue that teaching blind students in STEM will require a *situated learning context* [15], for which reason we developed our conceptual framework based on the integration of two theoretical paradigms: the *universal design for learning* (UDL) [16] and the *community of practice theory* (CPT) [17,18] approaches. Therefore, we propose the iterative relationships between CPT and UDL for blind-accessible STEM education (Figure 1), which we will now explain.

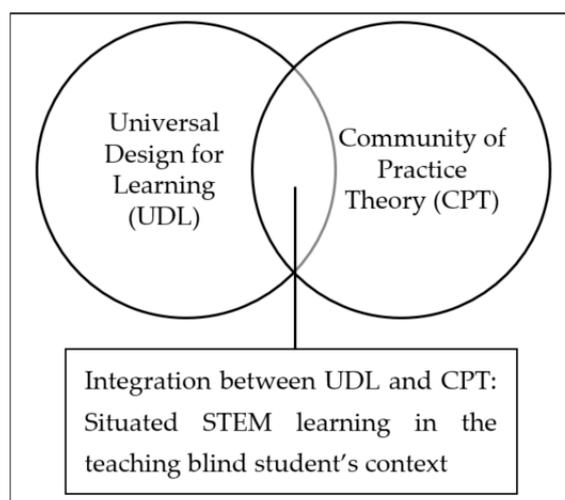


Figure 1. Integration of universal design for learning (UDL) and community of practice theory (CPT).

2.1. Universal Design for Learning (UDL)

Originally established in the field of architecture, universal design [16] aims to develop, from its initial planning stages, spaces and structures that could be accessible to all users regardless of their physical and/or mental needs [19]. Inspired by this assumption, the Center for Applied Technology (CAST) developed the universal design for learning (UDL) framework. UDL is based on three main principles that consider three main brain networks: (a) recognition networks (provision for multiple means of engagement for and by students); (b) strategic networks (provision for multiple means of representation for and by students); and (c) affective networks (provision for multiple means of action and expression for and by students) [20]. UDL has been used as a conceptual framework to analyze STEM accessibility in early childhood and in elementary and secondary education [21–26]. Thus, UDL may be a potential way in which teachers can encourage accessible STEM education for all their students, including blind students.

2.2. Community of Practice Theory (CPT)

Within the community of practice framework [15,17,18], *situated learning* theory [15] suggests that learning happens in a specific place and context. In a STEM classroom (the place) students apply knowledge and translate the information to a given application (the context). Communities of practice have been defined [17,18] as types of learning communities, available everywhere, and in which learners are often changing in their levels of expertise and interest. In this sense, learning is a social and situated act in which learners try to become part of different communities. In order to facilitate this learning process, members of this community should consider that they must incorporate these fundamental elements and actions: (a) learn and develop practice based on an existing body of knowledge; (b) create new knowledge in the domain; and (c) take action as a community to accomplish common goals [20]. This aspect is particularly important when referring to blind students as it presents a common enterprise in which all members of the community are actively engaged in each other's growth and success.

2.3. Situating How Blind Student Learners May Approach STEM: Integrating UDL and CPT

We posit that teaching blind students in STEM will require a situated learning context that iteratively guides UDL approaches; together, they can serve to minimize generalized approaches to teaching STEM. The UDL approach claims to offer accessibility for all. We understand the limitation that this statement can have because it may not necessarily consider the individual needs of blind learners and it can run into the danger of becoming a form of generalization and normalization that could re-enact exclusion [19,27]. This may be of particular concern for areas in STEM education where persons with disabilities, along with women and students from racial and ethnic groups (e.g., Blacks, Hispanics, and American Indians or Alaskan Natives), are often marginalized [29]. We maintain that a balance between the place, the context, and the multiple means of engagement/representation are needed to help garner interest in STEM.

2.4. Researchers' Positionality

We both approached this study recognizing that we are sighted people: our experience may differ from those who are blind but we did strive to listen to the narrative of the blind community, analyze their learning experiences in NFB EQ, and finally share our knowledge and discoveries with educators who are not blind. Establishing a relationship with the participants of this narrative inquiry created the necessary conditions to allow their voices to be heard and engender trust. Learning from the blind community and about the learners' perspectives led us to consider how STEM content can become more accessible and situated in the secondary education classroom.

3. Materials and Methods

3.1. Research Design, Participants, and Sampling

This research is a narrative inquiry and was approved by the University Institutional Review Board (protocol number irb-7658, and approval date of 06/17/2016). A narrative inquiry was selected as the methodology for this study because we intended to develop case-centered research [6,7] focusing on the experiences of the NSF EQ summer program teachers. We wanted to not simply explore the content of these blind students' teachers' narratives, but rather interrogate the intention and language [29,30] used to retell their experiences from the NSF EQ summer program.

This study entailed a long-term involvement [32] in the culture of blind youth. We approached the stories of the blind students' teachers as lived experiences [6,7] and we have strived to understand how these narratives could influence their approach to teaching and garnering interest in STEM among their blind students. We attempted to place our experiences from STEM education, curriculum and instruction, and cultural studies into a narrative interview. This involved an intensive interaction

with the narrators in order to explore their memories and understand their experiences [32–34] from developing and teaching these NFB EQ summer programs.

Theoretical and purposeful sampling [35] guided our efforts in selecting the five participants of this study: (a) one sighted university-based engineering professor, William (pseudonym); (b) one teacher of the blind who is blind, Nicole (pseudonym); (c) one sighted tactile artist and teacher with 20 years of experience teaching blind students, Abby (pseudonym); (d) one sighted university-based researcher and engineering professor (Idalis) who acted as teacher–researcher in this study; and (e) one sighted postdoctoral research fellow in STEM education, inclusion, and policy (Marialuisa) who acted as researcher–participant in this study. Pseudonyms have been used to refer to three teachers in this study (Abby, William, and Nicole), with the exception of the authors of this report, Idalis and Marialuisa.

This sampling can be defined as a critical and sensitive case [33] to “permit maximum application of information to other cases [. . .] to attract attention” [33] (p. 102) to the STEM education of blind students, who are traditionally marginalized in these fields. We chose to collect data and analyze existing data from these five participants in order to disseminate what we learned from this particular experience to a broader high school educational community.

3.2. Measures

For the purpose of this research, we collected and analyzed data in the form of (a) the NFB lead teachers’ field notes, (b) the lead teachers’ individual narrative interviews (the Idalis, William, Nicole, and Abby), (c) the teacher–researcher’s and the researcher–participant’s reflective journals (the authors), and (d) the lead teachers’ and the researchers’ collective narrative interviews through a focus group discussion (Idalis, William, Nicole, Abby, and Marialuisa). We also engaged in member-checking sessions, in which we explained the narrative research with the participants and discussed our narrator–listeners relationship [6,7]. We conducted member-checking sessions after each cycle of coding and after we had written the first draft of this manuscript, which helped us to develop the ethical attitude [33] and explain our interpretive process [6,7].

The field notes included information from the teachers during their week-long STEM informal education program instruction and from the teachers’ self-reflections. We conducted both individual and collective (focus group [36]) phone and face-to-face narrative interviews with the teachers participating in this study. These interviews developed around four main topics: (a) an explanation of the reasons why the teachers opted to instruct a cohort of blind students during a STEM informal education program during the 2013–2016 period; (b) an explanation of what the teachers learned from this teaching experience; (c) an explanation of how teaching STEM to blind students in the last three years changed their view on teaching in general; and (d) their recommendations to other high school teachers.

The focus of this narrative inquiry was the story of each teacher and each researcher who participated in NFB EQ and in the study. The aim was to create a more equitable relationship between the researchers and the teacher participants, “by subjecting the researched and the researcher to an analytical lens” [7] (p. 423). We sought confirmation of individual narrative data through the comments we recorded during focus group discussions, which reflected “the group nature of data collection and its influence on shaping individual comments” [36] (p. 131).

3.3. Analytical Procedures

Due to the multiplicity of data collected, we used two data analysis procedures with a software program designed for qualitative and mixed methods data analysis, MAXQDA 12. The first data analysis relied on conversation analysis (CA) to investigate “the structure and the process of social interactions” occurring during the narrative interviews and the focus group discussion [37] (p. 534). The symbols used for the audio transcriptions were adapted from Perkäylä and Ruusuvoori [37] (p. 540). There are three main assumptions to consider when analyzing talk through CA, which are

“(a) talk is action; (b) action is structurally organized; and (c) talk creates and maintains intersubjective reality” [37] (p. 534). In addition, we used thematic analysis (TA) to identify verbal or visual patterns in the field notes, personal narratives, and teachers’ artifacts in order to develop appropriate codes [38]. The combination of conversation and thematic analysis ensured a rigorous data analysis process [39].

We proceeded with the transcription of all audio recordings using the transcription symbols for conversation analysis, which provided a deeper level of investigation of the structure and process of social interaction among the participants of this study [37]. In the first cycle of coding, we provided descriptive information and organized the data according to five main categories proceeding from our main data collection technique: personal narratives, interviews, focus group, and field notes [40]. Then, we included analytic memos [41] with comments and reflections for each category. The analytic memos served as an additional method to generate codes and categories [41] while reflecting on the positionalities we established in relation to the data.

Before proceeding to the second cycle of coding, we used thematic analysis to identify the prevalent thematic and descriptive statements [41] guided from the participants’ stories and from our own stories. In particular, we focused on the section of data from which statements emerged that were related to instructional strategies and teachers’ perceptions, prevalently guided by our research questions. These two thematic statements allowed us to consider the next step in coding.

The second cycle of coding was necessary to re-organize and re-analyze the data coded through the first cycle conversation analysis [41]. A mix of theoretical, structural, and patterned coding guided us in this second step of the analysis, in which we systematically linked all categories and subcategories with the central/core category [41]. As a result of this second cycle, we identified six emergent thematic categories. At the end of each cycle of coding, we drafted a preliminary findings document that we shared with the participants of the study for member checking.

3.4. Limitations

The main purpose of this study was to understand ways in which secondary-level educators can foster interest in STEM among blind students. In particular, we intended to learn about instructional strategies and teachers’ perceptions that could improve STEM teaching in secondary education settings involving a blind and historically marginalized student population. We recognize that the study setting—the NFB EQ STEM informal education program—could be radically different from the general high school education setting to which we are attempting to transfer this knowledge. However, we believe that such a setting has provided the opportunity to explore strategies and consider perceptions that otherwise could not have been studied in a regular high school environment.

In addition, we considered that the teachers in this study could have experienced uncomfortable feelings about sharing their personal stories, their teaching methods, and their perspectives of blind students. Moreover, the hierarchical relationship among the teacher participants in this study may have created a potential risk for coercion during data collection, data coding, and analysis. To avoid these potential risks, we periodically checked with the participants and shared preliminary findings during focus group discussions and member-checking sessions.

4. Results

We have situated and provided the context of our findings through the narratives of our participants. This purposeful inquiry has allowed us to elevate the voices of blind students through the stories of their teachers in the NFB EQ experience.

4.1. William

William is a sighted university-based engineering professor. He is a former science high school teacher. For him, stepping back into a high school setting was a way to recapitulate his journey as a youth educator. What particularly influenced him from the NFB EQ program was the learning opportunity that he developed in teaching in such an informal education setting. Each edition,

developed over these years, was different. However, in each situation he remembered how he would have liked to draw upon his engineering and education training to look for effective instructional strategies: “We just get the special ed. training. We’d have one class in secondary education licensure for special ed. training, but it didn’t get into some of those things very much too.” (focus group, file 01) According to William’s perspective, it emerges that the academic teacher training for future engineering educators must consider all students as one homogenous group, without accounting for the specific situated learning experience that each of them needs. Such an approach determines a generalization in instructional practices and strategy for approaching blind and other students in a high school setting.

4.2. Nicole

Nicole is a teacher of the blind who self-identifies as blind. Her turning point was when she was pursuing chemistry courses in high school and the difficulties that she experienced in learning this topic in her high school. Her struggles motivated her to advocate and specialize in various special education programs for children and youth ages 3 to 22 years. She is an educational consultant for disabilities and STEM education. To use her own words, what she tries to do is “to provide an opportunity where 100% of the information is accessible to the kids” (personal narrative, file 04). Nicole’s approach developed from personal experiences. She recalled that in her chemistry class “I was rarely permitted to participate in the labs” (teacher’s interview). She also added, “So, I think one of the things that we just don’t get enough of, and you kind of can’t get enough of in four years in a [classroom] setting, is experience. Um, and real-life experience. [. . .] I would say apprenticeship would be the key” (teacher’s interview, file 01). For Nicole, designing lesson plans that are totally accessible for blind students is one of the most important factors for enhancing students’ understanding of STEM concepts and for providing practical experiences for the blind.

4.3. Abby

Abby is a sighted tactile artist, botanical illustrator, and teacher of the blind. For Abby, it is very important that all her artwork is clear and accurate for all audiences. Abby’s turning point was when, over 30 years ago, she began to wonder if some of her low relief slate pictures would be understood by a blind person. In seeking her answer to this question, she became an educator of art for the blind and has done so for the past 20 years. When describing her interactions with blind students, Abby argues: “for me, it (one-on-one attention) would mean teaching through touch and verbal instruction an entire concept with the student from start to finish” (member-checking session). To assist the first and Marialuisa in understanding what such “one-on-one attention” means for blind students, during the member-checking session Abby provided a hypothetical example: “For instance, a [high school] teacher is going to talk about battle strategies used in the Civil War. The TVI (teacher visually impaired) is called in to make sure the student has the formative knowledge of maps and how they work. The student and TVI make a map of the area together [ahead of time] along with icons that will represent the forces at work in the battle. When the [blind] student goes to class, the [high school] teacher is prepared to verbally describe the action [using the tools developed] so that the student can act it out on his map as the events unfold.” (member-checking session, file 14) From Abby’s description, we understand that one-on-attention to the blind student is not simply sitting next to the students and taking notes on their behalf, but rather it entails a constant collaboration between the high school teachers and TVI teachers in order to promote real participation in the classroom. As Abby commented: “I think that all too often we talk to our [blind] students and they converse at one level and so it is easy to miss that many of the words they [blind students] use . . . don’t always have a concrete meaning for them [blind students]. So, when we ask them [blind students] to do something concretely, it is a whole new experience that they [blind students] need time to figure out. I think it would be similar to anyone working with a new vocabulary.” (member-checking session, file 01)

4.4. *Idalis*

Idalis is a sighted university-based researcher and engineering professor. Her focus on disabilities started when she was 13 years old when one of her friends in school suffered an accident that left him a quadriplegic. Seeing first-hand his struggles throughout his life and education, as well as the struggles of other “disabled” friends, left her wondering about the inequities existing in the educational system for students with disabilities, particularly in STEM. She also empathizes with the struggles that minorities in STEM face as she too is a minority in engineering (Latina, first-generation, female, bilingual, and bicultural). The first step in her narrative about her three-year experience with the NSF EQ project was to reflect on her role as a teacher and researcher:

From 2013 to 2016, I directed the design and organization of a series of STEM informal education summer programs for high school blind students organized by the National Federation of the Blind (NFB) funded by the National Science Foundation (NSF). The interaction with the teachers and students helped shift my understanding of how STEM content should be taught to a wider range of learners. (Idalis, reflective journal)

Idalis realized that she couldn’t assume that blind students participating in these programs own the basic STEM content knowledge required by their grade level. For example, drawing a curve is a concept that most students in the U.S. start to become familiar with since kindergarten. However, any high school teacher cannot take for granted that a blind student acquired this knowledge previously. In order to create a common practice that includes blind students in the STEM teaching–learning community, teachers need to consider a blind student’s background knowledge and continue repeating these concepts in subsequent modules.

Taking into consideration the STEM knowledge of the blind students participating in the NFB EQ program, Idalis pondered upon the potential associations between blind students’ background knowledge and the challenges/limitations present in current STEM secondary education curriculum and educational systems. “They’re blind students—Idalis posits—so used to being the notetaker.” (personal narrative, file 19) The “notetaker” is a common role that is unfortunately attributed to blind students attending regular high school classes, as Idalis discovered while engaging in conversation and forum groups with the other educators who participated in this study.

The roles that blind students play in the education setting are also connected to their family and community; Idalis comments that “It really depends on the parents, how they’re [the blind children] being viewed, and how do they embrace their [blind] identity in the process.” (personal narrative, file 19) The NSF EQ summer program gave Idalis an opportunity to develop relationships with the students and the author educators, which opened her perspective about the functions that each institution practices in the development of each blind student’s identity.

4.5. *Marialuisa*

Marialuisa began her narrative considering her positionality:

I approached this study as a Sicilian, first-generation college student, female, who is a multilingual and multicultural research associate and data analyst in curriculum and instruction. I bring to the narrative inquiry my experience in teaching, tutoring, and observing high school students in Italy and in the United States for the past 15 years. My area of expertise is in second and foreign language acquisition, diversity inclusion, and education of historic marginalization of underrepresented groups in society. As a multilingual, I considered that access to the blind students’ and teachers’ community of practices require a pivotal change in the way we verbally and physically communicate meanings to students. (Marialuisa, reflective journal)

When Marialuisa approached teaching the first time, she reflected her traditionalist training. Similar to what William described, she attended general courses in which educators are brought to

consider special students as a homogenous group, and accommodations are described as a generic set of best practices. Interacting with Nicole and Abby, Marialuisa has been exposed to a completely different perspective on the education of blind students, in which the use of descriptive verbal instructions, hands-on activities, and one-on-one attention can significantly influence blind students' experiences in the high school setting. Marialuisa argues that "if we start thinking about disabilities, not only blindness in this way (implementing descriptive verbal instructions, hands-on activities, and one-on-one attention), these could really change the way we work in our classroom and we act in society. For example, these are things that need to be considered when we talk about differentiation of instruction and inclusion." (Marialuisa, member checking)

4.6. William, Nicole, Abby, Idalis, and Marialuisa: What Do Their and Our Narratives Reveal?

We extended the analytical lens to the narratives and the lived stories of the teachers and researchers of this study, engaging in the interpretations of their and our own stories. For our second cycle of analysis, we went back to these narratives and analyzed emerging and latent themes. We used MAXQDA 12 analysis of subcodes and a co-occurrence model to identify and visually represent the most recurrent codes and subcodes and their lines of interconnections. We used a priori guidelines established by the CPT and UDL frameworks as starting points but ultimately found additional emerging themes from the data. The themes that appeared to predominate when considering the three research questions presented earlier are (a) instructional strategies with main components of teachers' perceptions and awareness of accessible STEM education; (b) teachers' awareness, with main components in terms of inclusion, teachers' positionality, and students' identity; and (c) STEM knowledge, with main components in terms of the curriculum and education system. A summary of the primary categories or themes found from the personal narratives and focus groups regarding instructional strategies can be found in Table A1 in Appendix A. In addition, a summary of co-occurrence codes is provided for completeness in Table A2 in Appendix B—bolded numbers represent higher frequencies of codes identified from participant responses as shown in the double-digit values.

4.6.1. Instructional Strategies

The participants mentioned several instructional strategies that they had learned or used during the NFB EQ program, which, in their opinion, could be integrated into a secondary education classroom. Although targeting explicitly blind students, these instructional strategies have the potential to benefit all students in the classroom. Instructional strategies designed according to the different abilities of blind students have the potential to contribute to three main aspects: (a) increment students' sensorial experiences; (b) improve the effectiveness of teachers' lesson planning; and (c) contribute to students' reasoning development (Appendix A).

With permission from the teachers involved in this study, we have assembled a list of recommendations to help other high school teachers improve STEM outcomes for their blind (and all) students via instructional strategies. These have been subcategorized by the three identified themes for these findings:

1. ***Increment students' sensorial experiences.*** Within students' sensorial experiences, teachers indicated the importance of connecting the classroom lessons and content with students' mapping of the concept, object, or environment for learning.
 - a. Guide blind students tactually and complement this guidance with verbal descriptions in classroom activities—this can benefit all students. For example, if you are teaching about a cube, create a cube with different surfaces on the six sides of the cube. Describe to your students what each side represents and complement with a tactile drawing of the cube. If you need to present a graph to students, use a sewing tracing wheel and place a piece of paper on a rubber pad. Create the XY axis with the tracing wheel and represent the bar graphs or area under the curve by indenting or generating a tactile pattern that the blind students can use to mentally represent the image.

- b. Situate your students in the classroom during the first week of class or during a new instructional activity. Use cardinal directions to describe the physical space of instruction. For example, if you are talking about cardinal directions, walk to the front of the classroom and tap against the wall. Indicate verbally the north, south, east and west sides of the room. Complement this cardinal direction by creating a paper tactile map of the room that blind students can feel and use to mentally map the classroom and important areas of the classroom. Tactile maps can be created similarly to the “touch and feel books” that are commercially available by identifying different paper or cloth materials found in arts and craft supply stores.
2. ***Improve the effectiveness of the lesson planning.*** As a teacher beginning to develop your lesson plan, try to role-play as if you were a blind student learning about your course content.
 - a. Try closing your eyes and verbally describing to your students how to execute a task. For example, if you are teaching the concept of length, try to feel and describe the units on a ruler. Ask yourself if you can feel and represent the units through touch and mentally imagine them in your mind. If the answer is “No” or you find yourself having difficulty in doing so, then most likely your students (including blind youth) will too. Instead, identify simple and creative ways to introduce the concept of length to your students. For example, try notching a ruler and then repeat the exercise. Can you tactically identify the units through the notches? For other more complex STEM material, repeat the same exercise and find ways that your sense of touch complements what you are verbally describing to the students in your class. Remember that most of these exercises and materials could benefit not only blind students but all your students.
 - b. Explicitly ask blind students what they do and do not know before assuming their level of knowledge. For example, cut geometric figures and ask your students to identify them before teaching about 3-D structures in math. Ask students if they would know what a pH color change would be or represent. Complement the instruction with some color-coded sheets of paper or solutions whose color is detectable using free color-identification phone apps and/or provide verbalized descriptions of the colors so that all students can see and hear your descriptions about a color change due to pH.
3. ***Contribute to students’ reasoning development.*** Oftentimes, well-intentioned teachers attempt to include blind students in many classroom activities but are unaware of how to do so. Here are some simple suggestions that the teachers in this study shared with us.
 - a. Allow blind students to be their own spokespersons and mentors. Include blind students in leadership roles during team projects and assignments—do not assign them to the role of notetaker!
 - b. Allow blind students to learn through multiple means of representation and multiple means of action and engagement (e.g., UDL). For example, if there is an assignment due, allow them to turn in their assignments in ways that make sense to them (e.g., verbal descriptions of the learned content). Ask your students to provide some suggestions on how you could improve your presentation of the lesson in the future. Allow the blind youth to be empowered by actively participating in their learning.

In general, the teachers in this study agreed that simple changes in current instructional strategies would allow all students (including their blind students) to equitably benefit from STEM course content and empower them to learn STEM in ways that are relevant to their lived realities.

4.6.2. Teachers’ Awareness

The second emerging theme found was teachers’ awareness. It emerged as the most complex and articulated category of the study. Further analysis of the participants’ responses yielded two

subcategories: positionality and inclusion. First, the participants declared multiple times during the study that being part of this study gave them the opportunity to think about their positionality in the classroom, learn about their students' positionalities, and consider insider-outsider perspectives. Second, the accessibility of STEM content and tools and the perception of safety are essential for promoting the inclusion of blind students in a high school classroom. The teachers in the study reported that they do not believe that blind students are included or considered in the daily lesson planning routine. Also, the teachers indicated that based on their interactions with many blind students, blind youth do not feel safe to vocalize their educational potential in their formal high school classrooms. Inclusion in terms of accessibility and safety is considered a key element in allowing blind students to have an active role in the classroom (allowing for multiple means of engagement and representation of content knowledge to surface; UDL). Consequently, in an inclusive environment, it would seem more obvious to provide blind students access to those instruments that would allow them to work functionally and exactly as any other student [4].

4.6.3. STEM Knowledge

Participants of this study made explicit connections between the performance of blind students in STEM, the characteristics of the secondary-level STEM curriculum, and the teacher preparation process in the U.S. Through participation in the NFB EQ summer programs, the teacher participants realized that they cannot assume that blind students participating in these programs own the basic STEM content knowledge required by their grade level.

Based on these findings, several additional factors may need to be considered for more accessible STEM education for blind students: (a) systemic aspects of their education (e.g., what resources are available to support blind student education in the classroom); (b) considerations of what constitutes an accessible learning environment for blind students and what measures instructors can take in their courses; (c) understanding that current forms of instruction may lead to missed learning opportunities for blind students; (d) instructional strategies for blind education have the ability to empower all students in the class, regardless of whether they are blind or not; and (e) using instructional strategies for blind students that integrate concepts of STEM may be conducive to achieving this goal. While these identified subthemes may represent generalizable data, not all the information may be transferable. As such, the focus of this exploratory work relied more on the analysis of emerging themes (described above) as they lend themselves to being both transferable and generalizable for a wider variety of educators in STEM.

5. Discussion

This study aimed to elevate the experiences and voices of the teachers who led the STEM informal education program summer series: National Federation of the Blind Engineering Quotient program. Particularly, the use of NFB's community of practice apprenticeship model in combination with a curriculum designed around and taught using UDL principles presented a unique phenomenon that allowed us to propose potential relationships between the two frameworks in this study. For this exploratory work, we opted to study emerging themes from individual and collective narrative interviews, reflective journals, and field notes of the teachers, teacher-researcher, and researchers involved in this work.

Our first research question explored the teachers' and researchers' perceptions about STEM instruction for blind students. We found within these that sensorial experiences, the need for STEM lesson planning, and STEM reasoning development are important considerations for high school educators. For sensorial experiences, the use of accessible tools for tactile learning can help enhance STEM learning and interest of the blind students. For example, haptic tools (those that interface with the sense of touch) can provide additional ways in which to recognize and visualize concepts. Haptic tools can be developed from equipment such as 3-D printers and can serve to enhance and deepen mathematical understanding for students of all ages and backgrounds [42]. In physics [43] and

engineering [44,45], tactile-based learning experiences and tools can help highlight highly abstract, visual, and mechanical principles for students. For STEM lesson planning, blind students need to experience different modalities to help them understand fundamental concepts in STEM. For example, if teaching a concept of pH, students could use a pH strip and have an instructor indicate the color out loud for the blind student to annotate, as well as use an audio pH meter (found in companies such as Vernier). Finally, STEM reasoning is dependent on the modalities used to help this reasoning form. As Thinus-Blanc and Gaunet explain, “vision plays a crucial role in setting up spatial-processing mechanisms during a critical or sensitive period of development” [13] (p. 20). However, vision is not the only modality that can develop these mechanisms—it is merely the modality that is most often utilized. For example, to teach the concept of length, bar graphs were represented as strips of paper at different heights that had been characterized differently (e.g., punctures, indented stripes).

Our second research question explored the strategies that teachers used in this NFB EQ experience to engage their blind students in STEM. Many strategies used UDL premises, particularly multiple means of representation to present to their blind students the same concept in different audible and tactile ways. For example, to explain to students an environmental science problem, students were allowed to feel both a 2-D tactile drawing as well as a 3-D drawing of the same phenomenon. The 2-D drawing was made in a tactile pad made up of rubber foam and a ballpoint pen, whereas the 3-D drawing was made in clay and weaved with other arts/crafts papers. However, these experiences were situated with blind students’ experiences with STEM in their high school classrooms. Students shared how oftentimes their high school teachers made assumptions about their abilities and how oftentimes the content that was taught by a special education teacher was different when compared to their secondary education. As such, in order to develop instructional strategies for students, teachers of this NFB EQ experience indicated the importance of first assessing their own positionalities towards blind students’ abilities and current (not assumed) knowledge. A teacher’s positionality can help create consciousness and warrant a social change in the classroom [46], as well as provide a critical lens [47] by which STEM can become more accessible and situated for their blind students in the secondary education classroom.

Issues of inclusion and identity also emerged as possible deterrents during the design of an instructional STEM experience for blind students. As the teachers indicated, not having formal and informal instructive opportunities for their blind students to develop and form an identity around the concepts they learn in the classroom can negatively impact their academic and everyday activities [48]. In addition, these perceptions can hinder blind students’ ability to imagine themselves in STEM fields. More work is needed to further explore potential associations between identity, inclusion, and positionality for blind STEM education.

We approached this study considering that even though UDL opens up to the consideration of all students’ needs, we may risk recreating the binary dichotomy between normal and pathological, or normal students’ needs and pathological students’ needs. Therefore, instead of considering the vast range of human abilities present in the world’s population, we tend to privilege through intuition what is normal or universal, which is easy to misrepresent in any environment. “The resulting built environment is precisely what the social model criticizes—a world built without considering all ranges of ability.” [27].

Instead, we suggested looking at blind students from their diverse range of abilities and patterns of living, which are developed in their situated learning environments. Turning the gaze toward blind students may result in an alternative identification of problems and constraints during STEM learning without universalizing the potential solutions students may develop. Furthermore, as discovered through the interactions with blind students and teachers (both blind and sighted) from 2013 to 2016, incorporating UDL in the context of the secondary education classroom may require that blind learners have access to physical spaces and tools [49,50].

Also, for STEM education and for other researchers, keeping in mind the identity-first language when referring to blind individuals is key to engendering trust and conducting other ethnographic

studies of this nature. As more researchers move into the secondary education space and inclusive education, understanding the experiences and knowledge of all participants (e.g., students, key players) will help to situate the context to the voices provided in a manuscript. We hope this work will begin to shed light on both the education and research for blind students in engineering and other STEM subject matters.

6. Conclusions

The findings suggest that with modifications in instructional strategies for STEM, all students (not just blind students) can develop a higher interest in STEM and learn about and gain the same competencies in STEM. It furthermore suggests that secondary education instructors are in a unique position to allow or prevent these opportunities from occurring in their classrooms. As future inclusive learning environments are considered, it will be important to situate the context of the learners' identities and motivators, and consider the physical spaces and tools and the knowledge-forming activities that will benefit all student learners in the classroom. This work also presents a potential strategic order where principles of community of practice and universal design for learning can work synergistically to prepare and empower blind students to pursue STEM career pathways.

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Appendix A

Table A1. Summary of the primary categories or themes that emerged from the study.

Category	Descriptors Identified in the Category
Sensorial learning experiences in STEM (40%)	Accessible teaching tools Hands-on activities Tactile experiences Life experiences
STEM lesson planning (32%)	Backwards design Explicit instruction and descriptive language Connection between engineering and engineering education One-on-one attention to students Small student groups Differentiate instruction for a variety of learners Clear (self)assessment rubric for teachers Connection between art and engineering Begin from basic knowledge (not assuming acquired knowledge)
STEM reasoning development (28%)	Creativity Spatial reasoning abilities Problem solving Elicit answers from the students

Appendix B

Table A2. Summary of co-occurrence codes.

Emerging Themes Identified:	Subcodes														
	Systemic aspects of education	Accessible learning environment	Different level of blindness	Missed learning opportunities	Students' background	Teachers' perceptions	Empowering students through instruction	Teaching blind students is different compared to sighted students	Positionality	Instructional strategies used for blind students	Explicit instruction and descriptive language	Tactile experiences	Problem solving	Hands-on activities	Connection between STEM concepts
1. Instructional strategies	9	6	0	1	1	2	16	15	2	4	4	4	1	8	4
2. Teachers' awareness	3	6	4	4	8	4	17	5	6	13	1	2	9	1	1
3. STEM knowledge	3	1	1	1	0	0	3	3	0	2	0	0	0	0	1

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