The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #44435

Leveraging the CARE Methodology to Enhance Pedagogical and Institutional Support for Blind or Low-Vision (BLV) Learners in Electrical and Computer Engineering (ECE)

Aya Mouallem, Stanford University

Aya Mouallem (she/her) is a PhD candidate in Electrical Engineering, minoring in Education, at Stanford University. She received a BEng in Computer and Communications Engineering from the American University of Beirut. Aya is a graduate research assistant with the Designing Education Lab at Stanford, led by Professor Sheri Sheppard, and her research explores the accessibility of introductory engineering education to learners with disabilities. She is supported by the Knight-Hennessy Scholarship and the RAISE Doctoral Fellowship.

Trisha Kulkarni, Stanford University
Dr. Sheri D. Sheppard, Stanford University

Sheri D. Sheppard teaches both undergraduate and graduate design-related classes, conducts research on fracture mechanics and finite element analysis, and on how people become engineers. From 1999 to 2008, she was a Senior Scholar at the Carnegie Foundation for the Advancement of Teaching, leading its engineering study. Sheppard has contributed to significant educational projects, including the Center for the Advancement of Engineering Education and the National Center for Engineering Pathways to Innovation (Epicenter). Her industry experience spans Detroit's Big Three: Ford, General Motors, and Chrysler. At Stanford, she has served as faculty senate chair, associate vice provost for graduate education, founder of and adviser to MEwomen, and leads the Designing Education Lab (DEL), which aims to revolutionize engineering education. Her achievements have earned her numerous honors, such as Stanford's Walter J. Gores Award and the American Society for Engineering Education's Chester F. Carlson and Ralph Coats Roe Awards. She earned her PhD from the University of Michigan.

Leveraging the CARE Methodology to Enhance Pedagogical and Institutional Support for Blind or Low-Vision (BLV) Electrical and Computer Engineering (ECE) Learners

Abstract

There is a growing, yet relatively limited body of research exploring the experiences of learners with disabilities in introductory electrical and computer engineering (ECE) education. With the proven importance of introductory ECE education in influencing students' undergraduate interests and future career prospects in technology, the inaccessibility of the field to learners with disabilities poses an inequitable access barrier that further marginalizes these learners, often preventing them from exploring the field in the first place. In particular, as ECE largely relies on visual cues for designing, building, testing, and debugging hardware systems, ECE education is significantly inaccessible to learners who are blind or have low vision (BLV). Thus, it is imperative that we assess and evaluate any accounts of blind ECE learners to critically redesign ECE pedagogy to meet their preferences and needs and prioritize their inclusion. The Challenging and Rewarding Experiences (CARE) methodology is a recent framework that promotes an in-depth assessment of student-centric perspectives on ECE course offerings, with the intention of informing instructors of necessary change to be introduced to the course offerings to improve students' experiences and align their expectations with the planned course objectives. In this paper, we apply the CARE methodology to conduct a comprehensive analysis of the autoethnographic account of the first blind student to complete the introductory ECE course at our institution, Stanford University. This work also expands the role of the blind student to become a co-researcher, actively guiding the direction of this work while receiving mentorship from research team members on qualitative research methods.

In this work, we begin with the analysis of seven reflection journal entries written by the blind student and relevant discussion session notes recorded by the lead researcher. These data were generated and collected via the autoethnography method and analyzed by applying the CARE methodology, using a grounded theory approach, during which we completed open and focused coding. We then identify intersecting Challenging And Rewarding Experiences (CARE) areas that the blind learner faced in the introductory ECE course. Next, we compare these CARE areas to those that emerged from studying a group of 42 sighted students taking the same course with the same resources, as published in prior work. This comparison leads us to identify a new, fourth lens for the CARE methodology– namely, *inequitable* challenges, faced by the blind learner due to the inherent ableism of ECE education and the inaccessibility of its available resources (this is in addition to the original three lenses of the methodology: rewarding experiences, unproductive struggle, and healthy challenges). Consequently, based on the newly identified CARE lens in this work, we propose a preliminary list of good practices for inclusive institutional and pedagogical support for BLV learners pursuing introductory ECE education. We also believe that the CARE methodology can be used to amplify the voices of other ECE students with different disabilities to inform systemic change for inclusive ECE education.

1 Introduction

1.1 Disability in engineering education and professional fields

The 2023 National Center for Science and Engineering Statistics (NCSES) report *Diversity and STEM: Women, Minorities, and Persons with Disabilities* defines a person with a disability as someone who experiences difficulties completing one of the following activities: "seeing words or letters in ordinary newsprint (with glasses or contact lenses, if usually worn); hearing what is normally said in conversation with another person (with a hearing aid, if usually used); walking without human or mechanical assistance or using stairs; lifting or carrying something as heavy as 10 pounds, such as a bag of groceries; and concentrating, remembering, or making decisions because of physical, mental, or emotional condition." According to the same report, data on postsecondary degrees earned by persons with disabilities are very limited in comparison to other minority groups [1]. The report states that 65% of STEM employees with a disability had not attained a bachelor's degree. Among doctorate recipients with disabilities in 2021, individuals in engineering had the lowest rate of disability among all majors of study, at 8.2%. As the report highlights that 24% of the U.S. workforce is employed in STEM occupations, it remains imperative to address the consistently low numbers of students with disabilities pursuing engineering degrees in higher education.

There have been growing research efforts exploring the intersection of disability, participation in engineering fields, and broad engineering education. A recent literature review highlighted the relatively unexplored area of meaningful disability participation in engineering fields, focusing on four groupings of disability: physical, cognitive, behavior, and psychiatric. According to this work, most of the available literature still views people with disabilities in unfavorable light, often excluding them from participating in studies on technologies for disability, overlooking their much-needed insight, and treating them as unequal engineering partners in the design and research processes [2]. Another literature survey focused on ASEE publications noted that there was a significant lack of research focusing on disability as an identity and on the experiences of students with disabilities in engineering education [3].

Several works have explored the stigma, social exclusion, systemic marginalization, devaluation, and feelings of "otherness" experienced by students with disabilities in engineering education [4], [5]. These consequences were attributed to a variety of reasons, including the lack of role models with disabilities, educators' misconceptions about the students' abilities, lack of adequate counseling and institutional support, and the lack of accessible engineering and educational tools in lab settings [6], [7], [8], [9]. Noteworthy is focused and comparative work in civil engineering education which has seen particularly extensive efforts addressing disability (in comparison to other fields). For example, multiple projects have explored the experiences of students with disabilities in civil engineering programs in different settings, including the United States, Germany, and South Africa [10], [11], [12].

Ableism has always been prevalent in many fields of education, including engineering education. It entails discrimination against people with disabilities, often in favor of practices and preferences of able-bodied individuals; consequently, this reinforces the exclusion and marginalization of people with disabilities – the biggest minority group in the U.S. [13], [14].

With ableism in engineering fields still persistent, there has been commendable research aimed at improving the accessibility of engineering education for students with diverse disabilities. These works addressed multiple fronts, including the proposal of new tools and educator resources, informing policy decisions, and leading new research initiatives [15], [16], [17], [18]. On the tools front, Behm et al. presented an improved real-time tracking text display (RTTD) for deaf and hard of hearing students attending engineering lectures [19]. The University of Washington's AccessSTEM program developed a multitude of resources for educators to facilitate creating inclusive teaching environments in engineering [20], [21]. Moon et al. proposed several accommodations for students with different types of disabilities, including blindness, deafness, and cognitive disabilities in classrooms and labs across educational levels [22]. Moreover, policy efforts have also advocated for increased funding for workshops focusing on students with disabilities in engineering, as such inclusion is vital for economic prosperity and social equity [23]. Such efforts are crucial, along with the need for a more specific focus on different engineering fields to significantly enhance the accessibility of each field.

1.2 (In)accessibility of introductory ECE education to learners with disabilities

Electrical and computer engineering (ECE) education is among the less systematically explored fields in terms of accessibility to students with disabilities. As a rapidly growing field over the past two centuries, the design of ECE curricula did not often accommodate for disability access. In his reflection on the future direction of ECE education in 1971, H. H. Skilling, an influential figure in the development of ECE education at Stanford University, stated, "We must continue to train the practitioners of [electrical] engineering, and in addition we must help educate *all* serious students. This double responsibility lies before us." [24] In line with such hopes, it is necessary to include students with disabilities who are interested in ECE in such educational offerings.

Recent research has attempted to explore diverse inaccessibility gaps in ECE education. A VR tool simulating an electrical engineering lab was prototyped and tested with the goal of improving the experience of students with disabilities, especially those with mobility disabilities [25]. As for TronicBoards, it is a toolkit that was developed to support learners with intellectual disabilities in exploring circuit design [26]. In his autoethnographic work, Seo addressed three aspects of makerspaces that were inaccessible to blind and low-vision individuals: inaccessible instructions for toolkits, lack of multisensory modules, and a less tangible design of breadboards [27]. These areas involved electronic hardware prototyping and circuit design, which are main pillars of ECE education.

Such inclusive research efforts in ECE education are very important but are dispersed and few. We believe that ECE education requires a systematic investigation of its ableist resources, and that the experiences of students with different types of disabilities must all be explored in depth and documented to guide the development of pedagogical and institutional support mechanisms. Thus, in this work, we focus on the inaccessibility of ECE education to blind and low-vision learners (BLV) in particular, adopting a student-centric approach to source barriers that hinder BLV access to the field. This effort is part of a larger project extensively exploring how ECE education can become more accessible to learners who are BLV via the introduction of new technology, educational tools, and frameworks.

1.3 A student-centric approach to center the BLV learner's experience

Recent research has begun to address inaccessible aspects of ECE education to BLV learners, including tactile add-ons to electronic components, nonvisual soldering workshops, and 3D-printed circuit diagrams [28], [29], [30]. While a step in the right direction, we believe that a truly transformative re-design of ECE education to support BLV learners must stem from the learners' experiences first and foremost. It must adopt principles of co-design [31], [32], [33], where the learners, who are the primary stakeholders and users, end up influencing the design and research agenda by highlighting the most pressing challenges that they face in the field. We are spearheading this effort, adopting the autoethnography method to document in depth the experiences of the first BLV learner to complete the introductory ECE course, ENGR 40M, at Stanford University [34]. Such documentation is the first to exist in the field and aims to lay the foundation for similar efforts in the future, in order to develop BLV-inclusive measures that must be introduced to ECE education directly from student-centric feedback. In our referenced autoethnographic work, we explored the *design* decisions of introductory ECE education resources that make the field inaccessible, and we recommended BLV-inclusive design criteria for future engineering education tools accordingly, such as modular electronics, tactile labels, and multimodal feedback. In this current research, we attempt to explore the *pedagogical and institutional* aspects that can improve the BLV learning experiences in ECE education.

1.3.1 Autoethnography

Ethnography is a form of social inquiry and a qualitative research method that researchers have been adopting more frequently in engineering education research, as it allows them to closely observe and interpret how people interact, function, and behave in different social contexts [35], [36], [37]. Stemming from fields such as anthropology and sociology, ethnography entails the collection of data using a variety of methods, including observation, listening, and asking questions [38]. Autoethnography is an evolved subset of ethnography; it is a qualitative research method that centers the subjective, personal insights of a researcher as the main explored narrative, as situated in a specific sociocultural context [39]. Via autoethnography, the researcher becomes the primary source of data and can investigate and analyze the latter reflexively. This method holds particular promise in the context of our research, as it can help elevate and explore the marginalized, undocumented experiences of BLV learners in ECE education, away from oversimplification or generalization. In addition, as particularistic findings in qualitative research may hold greater value than generalizable ones, especially when studying marginalized narratives, autoethnography can elucidate specific insights from a sole BLV perspective in ECE education that can lay the groundwork for more comprehensive surveying of additional BLV experiences in the field [40].

In fact, autoethnography has been previously utilized in education research [41], [42], [43], [44]. In particular, it has also been used to seek and document the experiences of students with disabilities in making and STEM education [27], [34], [45]. By centering the role of participants with disabilities as the primary researchers in the process, autoethnography ends up fully aligning with the slogan "Nothing about us, without us" that has been adopted by disability activists and organizations for decades in a variety of fields, including education [46], [47], [48], [49].

To hone in on the importance of adopting autoethnography in an ECE educational context, we postulate that this method can uncover and emphasize the *lived curriculum* by BLV students in ECE education [50], [51], [52]. In reality, even with extensive prior planning, educators and disability support officers (DSOs) cannot fully predict the impact of their accessibility measures on the realistic experience of an incoming BLV student to an introductory ECE course. This difference between the educators', DSOs', and students' expectations and experiences gives rise to the aforementioned lived curriculum. We believe that autoethnography can afford educators and DSOs a deeper understanding of the reality of being a BLV student in an ECE context, in addition to providing a closer look at the impact of any BLV-accessibility measures integrated in the curricular offerings.

1.3.2 The CARE methodology

To provide structure for a student-centric analysis of the autoethnographic data, we adopted the CARE methodology, displayed in **Figure 1,** which we developed and applied previously for a student experience assessment in an introductory ECE course context [53]. This methodology categorizes the collected and coded qualitative student-centric data as challenging and rewarding experiences. It posits that the intersecting areas of the most **C**hallenging **a**nd **R**ewarding **E**xperiences, or **CARE** areas, are the most important areas to improve in order to better align what the students value and take away from the course with the educator-planned course objectives. In particular, the CARE methodology categorization sheds light on students' "unproductive" struggles and "healthy" challenges, in addition to what they find fulfilling and rewarding in their learning experiences. Given the access barriers that BLV learners face in ECE education, the CARE methodology can uncover and amplify such experiences, so that educators and institutions can crucially address such barriers to improve the learning process of BLV students in ECE courses.

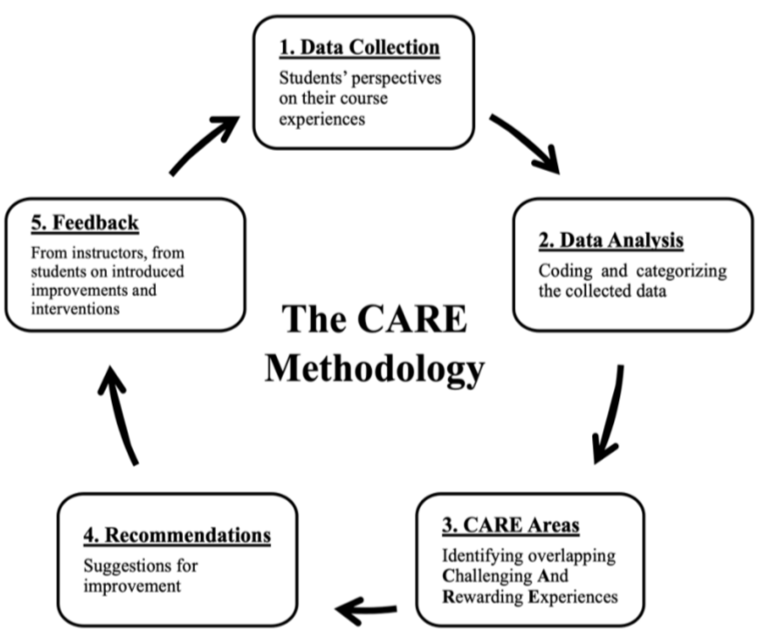

Figure 1. The iterative CARE methodology [53].

1.3.3 The introductory ECE course

The CARE methodology was recently applied in the context of the *same* introductory ECE course that the BLV student enrolled in and completed in this research work. Called *ENGR 40M – An Intro to Making: What is EE*, this is the introductory ECE and making course in the ECE course sequence at Stanford University. It is required as a core course for ECE majors and as an elective for other majors, such as Computer Science. The course incorporates multiple lectures and problem-solving sessions every week, in addition to weekly labs. In the lab, students apply introductory ECE concepts, such as Ohm's law, power, microcontrollers, filters, and amplifiers to build real-life, functional projects and devices. These include a solar-powered USB charger, an electrocardiogram, and a LED cube. The course has incorporated several curricular re-design iterations and new tools to improve its offerings for students, including a debugging simulator and journal [54][55]. The main goal of this course is to make introductory ECE education more experiential, realistic, and enjoyable for early ECE students. On average, the course welcomes more than 100 students every academic quarter and is usually offered year-round. Appendix A in the work [53] provides a detailed course overview, covering its learning outcomes, activities, and performance indicators. Bell and Horowitz also documented their re-design of the course pedagogy to increase learning motivation among the students [55].

In 2022, the CARE methodology was utilized to assess the experiences of 42 sighted students who were enrolled in ENGR 40M [53]. After collecting, qualitatively coding, and categorizing the data according to the CARE structure, five main CARE areas were presented:

- Understanding, analysis, and design of circuits
- Developing hands-on lab skills
- Exploring and simplifying complex systems independently
- Debugging
- Working independently with room for innovation

These were the course areas that students found the most rewarding but also significantly struggled with, and the referenced work delves into detail for each area. Researchers then presented a list of recommendations to address those CARE areas, in order to improve the learning experience of students in the course in line with its objectives. Therefore, in our work, we explore whether the CARE areas emerging from the BLV student's course experience overlap with the aforementioned areas and how they compare.

1.4 Deliverables

This work expands our prior efforts in documenting the experiences of a BLV learner in introductory ECE education. It provides the essential basis that can inform institutional and pedagogical improvements to increase the accessibility of ECE education to BLV learners. By adopting the CARE methodology to assess the BLV learner's experience with the course, this methodological choice also has implications for the use of the CARE methodology itself as an approach to expose systemic barriers to inclusive ECE education for learners with disabilities. Finally, this work addresses the uncovered BLV experiences in the studied introductory ECE course by proposing some recommendations for academic institutions, educators, and disability support officers (DSOs), directly sourced in a bottom-up manner from the BLV student's experiences, to transform different aspects of the BLV learning experience in ECE. The aim of this work is to set the foundation for additional, future work by researchers and educators in the community to expand these accessibility efforts in ECE and to add to the non-exhaustive documentation of BLV challenges and relevant recommendations in the field.

2 Positionality

The authors of this work bring forward a diversity of experiences that overlap with and contribute to different areas of this work. Thus, we briefly highlight our relevant backgrounds.

Aya Mouallem is a sighted researcher and fourth-year PhD candidate in Electrical Engineering with the Designing Education Lab at Stanford University. She focuses on designing new technology-based tools and frameworks to improve the accessibility of ECE education to BLV learners. Mouallem has collaborated with BLV community members and organizations throughout her research projects, including needfinding, tool co-design, and evaluation. She also mentors blind undergraduates in engineering research at Stanford, and she has prior teaching experience in design and engineering, including belonging to the teaching team of ENGR 40M (the course under study). Mouallem mentored Kulkarni on the use of qualitative research methods in this work.

Trisha Kulkarni is currently a master's degree candidate in Computer Science at Stanford University. She was the first blind student to complete ENGR 40M as an undergraduate requirement. She completely lost her vision during her early teens, which necessitated her use of nonvisual techniques during her education. While she is proficient in Braille, she primarily uses digital screen readers to complete schoolwork. Kulkarni's conflictingly empowering and isolating educational experiences fuel her dedication to inclusion in STEM education as a teaching assistant and mentor to blind students nationwide. Kulkarni explores her experiences in ENGR 40M via autoethnography in this work.

Sheri D. Sheppard is an experienced Mechanical Engineering educator. Many of her courses involve project-based learning and in-class hands-on exercises. Adapting these exercises for her students with disabilities, including BLV students, has been challenging, and not always successful. Through her teaching and in her research, she is keen on expanding our collective understanding of how to make engineering education both exciting and accessible.

In this work, Kulkarni used the pronoun "I" to describe her autoethnography experiences in any featured quotes. Mouallem set the project groundwork and coordinated the research process. Mouallem and Kulkarni collaboratively analyzed the data, and in such contexts, they used the pronoun "we." Sheppard mentored the rest of the authorship team and provided education-focused feedback throughout the process.

3 Methods

3.1 Data collection

This section covers our efforts in relation to Step 1 of the CARE methodology as displayed in **Figure 1.** Our work primarily relies on the autoethnographic data that was generated by Kulkarni with the guidance of Mouallem. The autoethnography project was proposed after Kulkarni completed ENGR 40M in 2022. Thus, the autoethnographic method was employed retrospectively, starting approximately one month post-course completion. Data collection was completed over six months, during which Kulkarni wrote journal entries and participated in regular follow-up discussions with Mouallem as follows.

To facilitate this data generation process, Mouallem prepared a list of optional guiding questions as thought-primers that Kulkarni could use to address different aspects of her experience with ENGR 40M in her written journal entries and during the subsequent discussion sessions. The list did not attempt to evoke any specific types of positive or negative experiences, and Kulkarni often ventured beyond the questions on the list with her own reflection topics. Kulkarni tackled one week's worth of course content at a time, reviewing that week's course material, including homework submissions and pre-lab assignments, and reflecting in her written journal entry, as shown in **Figure 2**. Then, Mouallem and Kulkarni would meet, sometimes more than once, to discuss that week's entry. Mouallem would probe with more questions during the discussion sessions, and she took the lead on drafting detailed discussion notes. In addition to retrospectively generated data, we relied on artifacts from the course, including class lecture recordings and lab handouts and manuals.

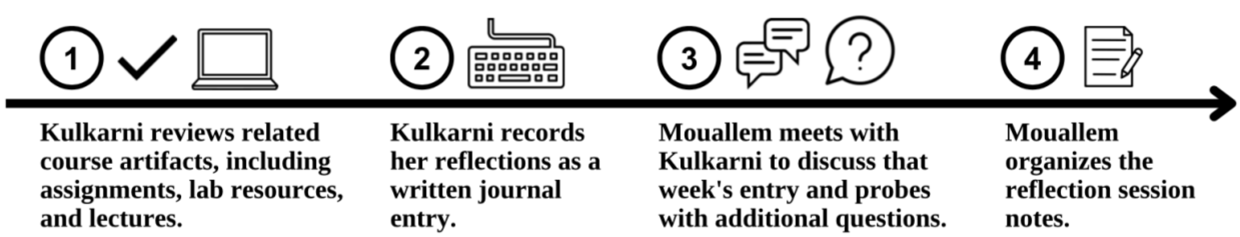

Figure 2. The data collection steps adopted for every week's worth of course material by Mouallem and Kulkarni.

Mouallem and Kulkarni conducted their discussion sessions over Zoom, as they were in different time zones at several points. We consolidated Kulkarni's journal entries and the discussion notes taken by Mouallem using a Google Doc. In total, the collected data amounted to 7,239 words, in the form of seven journal entries (which we will refer to as JE in this work) and discussion notes of more than 10 discussion sessions (which we will refer to as DS). These data served as our primary dataset for this work. We provide quotes from these journal entries and discussion sessions between quotations in the **Findings** section.

3.2 Data analysis

In this section, we explain our application of Steps 2 and 3 of the CARE methodology as displayed in **Figure 1.** To analyze the collected data from a student-centric perspective, we adopted a grounded theory building approach, as it emphasizes the inductive development of hypotheses directly from the collected data itself, rather than relying on literature to define analysis directions [56], [57]. In fact, the grounded theory approach was a very suitable choice for analyzing this work because an extremely limited body of literature, prior to our efforts, has explored and documented the experiences of BLV learners in introductory ECE education, especially using autoethnography. Therefore, we were not able to create a solid basis using prior literature findings to guide our analysis deductively.

In line with the prior application of the CARE methodology in [53], and to commence data analysis, we inductively generated qualitative codes based on our collected data to represent clustered themes and areas in the autoethnographic data. In fact, we first completed a round of open coding, where each of us (Mouallem and Kulkarni) separately generated as many codes as possible, arranging them in two separate codebooks. These codes were words or phrases representing similar data and ideas [58]. Next, we met and compared our codebooks, and we resolved any missing or conflicting codes. After that, we were able to merge our codebooks into one. As a next step, we completed a round of focused coding using the merged codebook, where we began to draw potential connections between our codes and recorded them as memos. We explored connections based on the situational context in which certain experiences occurred, social interactions relevant to the experience, and the consequences or effects of any (in)action taken [59]. This enabled us to cluster similar codes into more abstract categories.

At this stage, upon the completion of Step 2 of the CARE methodology, we had generated 23 different codes and 104 relevant sub-codes addressing all possible areas of Kulkarni's experience in the introductory ECE course. To complete Step 3 of the methodology (Identifying the CARE areas), we then set up a categorization structure representing the codes of challenging experiences and another representing the codes of rewarding experiences to further cluster the identified codes. For example, codes representing challenging experiences included "lack of [accessible schematic] labeling," "debugging," and "inability to document understanding." Codes representing rewarding experiences included "independence," "[collaborating with a] lab partner," and "multimodal representation." Some codes were placed simultaneously in both structures, giving rise to the CARE areas of Kulkarni's experience in the introductory ECE course, which we discuss in the **Findings** section.

Applying the categorization approach of the CARE methodology, each of these structures further categorized the student experiences into "cognitive, affective, metacognitive, and pedagogical categories", as influenced by Bloom's taxonomy, Fink's taxonomy, and the work explained in [53], [60], [61]. The categorization structure for codes representing challenging experiences is shown below in **Figure 3**.

Categories of Codebook 1 (Challenges)										
Cognitive			Metacognitive					Affective		Pedagogical
Remember (B)	Understand (B)	Apply (B)	Analyze (B)	Evaluate (B)	Create (B)	Integrate (F)	Learning how to learn (F)	Caring (F)	Human Dimension (F)	

Figure 3. Categorization structure of codes representing challenging experiences into cognitive, metacognitive, and affective experiences, in addition to pedagogical factors. Categories labeled with (B) are extracted from Bloom's taxonomy, and categories labeled with (F) are extracted from Fink's significant learning outcomes.

With this structure, we were able to assess Kulkarni's experiences as a BLV student in ENGR 40M more comprehensively, and we also began to notice *inequitable* challenges that Kulkarni had to deal with particularly due to her disability. We explore these areas in detail in the **Findings** section.

3.3 A note on the accessibility of the data analysis process

Qualitative coding software packages are often partly or completely inaccessible to digital screen readers, which are text-to-speech software packages that improve the accessibility of digital PC work to BLV users. Therefore, we adopted workarounds from work by Aishwarya that highlighted the exact issues that we faced with coding software inaccessibility [62]. As a result, we used Microsoft Excel to code the data, as Excel was accessible to a screen reader. Kulkarni is a blind researcher promoting academic research about her disability, and while achievable, our research process was more tiresome and involved, in comparison to a conventional, inaccessible coding software process. This demonstrates the dire need for accessible research tools to invite more BLV researchers to efficiently conduct valuable research on their experiences.

3.4 Validity practices to improve the research quality

While autoethnography is a deeply subjective method, it remains a vitally important approach to documenting individual narratives that are traditionally marginalized in engineering education. Autoethnography is subject to the traditional criteria of validity, adhering to the fact that the writing must "evoke in readers a feeling that the experience described is lifelike, believable, and possible" [39]. In our work, we conducted numerous discussion sessions of Kulkarni's journal entries to record detailed experiences that the latter faced during the introductory ECE course, in order to collect sufficiently comprehensive data that can evoke a realistic picture of Kulkarni's experience for the reader of our work. Moreover, as autoethnography relies on the reflexive analysis of one's experiences in relation to the sociocultural contexts surrounding them, we attempted to achieve reliability by analyzing our collected data while situating it in the context of ENGR 40M and in relevance to the heightened emotions and awareness of identity that Kulkarni elaborated on, especially in comparison to sighted students' experiences [63].

Finally, we adopted multiple validity recommendations by Johnson and Wolcott, including methods triangulation, investigator triangulation, and seeking feedback from experts [40], [64]. Our work in [34] elaborates on the adoption of these validity methods in our autoethnographic process. It is important to reiterate, according to Johnson, that particularistic findings may reveal more valuable insight than generalizability in qualitative research. Our research closely aligns with this statement, as we believe that the specific findings that emerged from Kulkarni's experience are necessary to launch needed documentation efforts for the experiences of marginalized BLV students in ECE education.

4 Findings

Via the analysis of the autoethnographic data representing Kulkarni's experiences as a BLV student, we identified *five* main CARE themes, consolidating the codes that simultaneously appeared in the categorization structures of challenging *and* rewarding experiences. The areas are:

- Understanding, analysis, and design of circuits
- Experimental learning methods for improved accessibility
- Developing hands-on lab skills
- Interactions with stakeholders
- Exploring and simplifying complex systems

We first discuss each CARE area in detail, then we compare the current CARE areas listed above, generated from the BLV student's experience with those identified in the sighted students' experiences in [53] and listed in the **Introduction**. We also elaborate in the **Discussion** section on the grounding of many challenges that Kulkarni faced in the inherent ableism of ECE education.

4.1 The five CARE areas derived from the BLV student's experiences

4.1.1 Understanding, analysis, and design of circuits

ENGR 40M primarily relies on circuit schematics and system diagrams to introduce and apply basic circuit theories. For example, in the first assignment of the course, the enrolled students usually navigate a variety of simple circuits, consisting of a power source, resistors, and wires, to apply Kirchhoff's Current Law and Ohm's Law. The course also introduces different electronic components throughout the academic quarter, including capacitors, inductors, and transistors. In the case of the latter, students learn the flow of current into/out of at least three terminals of the transistor (gate, drain, source), which also requires a visual exploration of how the transistor is connected in the larger circuit. Kulkarni reflected on her experiences with such curricular content.

The disability services officer (DSO) who worked with Kulkarni prepared a limited number of square cardboards with Braille printouts of the schematics of main electronic components used in the introductory ECE course. Examples of these cards are shown in **Figure 4.** While the Braille cards allowed Kulkarni to explore the component schematics and place them in order on a surface to create a circuit schematic, "exploring tactile circuits for the first time during class [was] hard." Moreover, the course material was primarily presented in slides, which were explained in recorded videos, as the class adopted a flipped class format. Therefore, the schematics in those slides were inaccessible to Kulkarni without another person being present and describing such schematics out loud to Kulkarni. As she reflected on these struggles with the inaccessible format of the course content, Kulkarni maintained that “once [she was] on the same ground regarding [the] photos shown in recordings of the lectures, she became more comfortable with the concepts.” She also reflected on how she went through a “schematic a lot until it made sense conceptually.” At that point, Kulkarni would feel that she had established a solid foundation in understanding the material, and that brought her feelings of pride and accomplishment.

Among the electronic components that the course introduced, Kulkarni found transistors to be particularly “cool but challenging.” As the transistor required the student to understand the current flow through its different terminals, Kulkarni had to meet with a visual descriptionist (a student who had previously taken this course and who was hired by the DSO to provide visual description to Kulkarni of the course content) to describe the layout of the terminals and talk Kulkarni through the direction of the current flow into/out of each terminal and in the rest of the circuit. Kulkarni found it challenging to document such understanding, as the Braille printouts of the transistor did not incorporate tactile representations of these different current directions. While Kulkarni attempted to take typed notes on her laptop about the transistor functionality within a larger circuit design, it was difficult for her to make sense of these notes later on, when the visual descriptionist was not present to refresh her memory, and when there was no layout of the larger circuit – only a schematic of the sole transistor. However, despite these challenges that accompanied learning about transistors, Kulkarni expressed how rewarding it was for her to learn how transistors represent binary logic and apply such knowledge in proposing a design for a decorative LED cube for one of the lab projects.

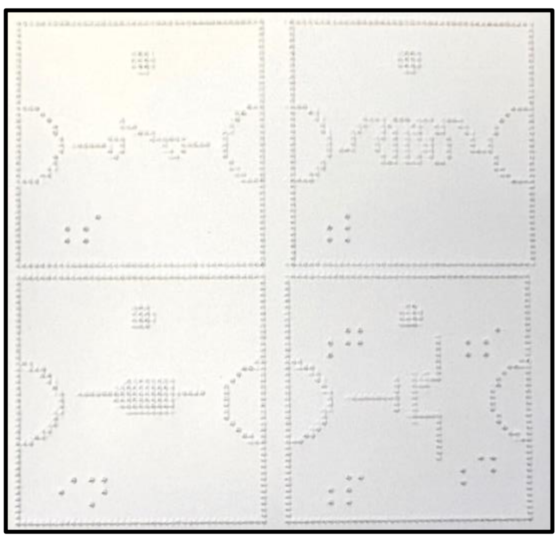

Figure 4. Braille card printouts of different electronic components.

Therefore, this CARE area highlighted some mixed experiences that Kulkarni had while building her understanding of circuit theories and utilizing them to design and analyze circuits. The inaccessibility of many aspects of these experiences, such as the limited availability of Braille printouts and missing tactile representations of specific concepts, added difficulty to the student’s learning experience. Nevertheless, she was able to extract rewarding moments from these learning processes.

4.1.2 Experimental learning methods to improve accessibility

As Kulkarni was the first BLV student to complete this introductory ECE course, she had to work with the course teaching team, the DSO, and the visual descriptionist to experiment with alternative learning methods, given that many of the conventional approaches adopted in electrical engineering education are inaccessible.

Based on the student's experience, there was no single ideal approach that could make up for the existing inaccessibility. Therefore, Kulkarni combined multiple methods to overcome as many inaccessible aspects of the course as possible. For example, she recalled how she used the tactile, Braille printouts, stating, "[I used them] as a launching point, but I quickly left them behind in favor of talking through concepts." In fact, she "found it efficient and helpful to meet and talk with lab [instructors]," but she also felt that the "combination of talking through concepts and using hand-drawing was the best." To elaborate on the hand-drawing approach, Kulkarni and the teaching assistant experimented with using their index fingers to trace the schematic of a circuit design on the palm of Kulkarni's hand during office hours. They found this to be an efficient alternative when tactile printouts of circuits were unavailable. In reality, that often was the case, since every week's course content incorporated tens of schematics of different circuitry. As a result, producing all of the schematics in a tactile format was very resource- and time-consuming. Thus, utilizing the hand-drawing approach became the norm. For instance, the hand-drawing technique was helpful to further Kulkarni's understanding of the functionalities of a transistor. Kulkarni explained, "It was harder to understand [transistors] online [via a recording or call] and was a bit easier in person when the descriptionist just drew it out… It was relational and helpful to the furthest extent… Though, having someone draw on my hand was hard to remember later because I couldn't document that." Therefore, the mix of tactile cards, talking through concepts, and hand-drawing created fulfilling experiences for Kulkarni in the moment, though it was not always feasible to draw upon those learnings for revision later on.

The approaches highlighted above also provide insight into the importance that Kulkarni placed on the multimodality of information and feedback in her learning process. In particular, Kulkarni found fulfillment in relying on haptic and audio-based feedback, rather than inaccessible, visual data. For example, Kulkarni preferred to explore circuit schematics, which are primarily visual, by tracing tactile drawings on her hand or by relying on Braille printouts. She also appreciated having access to physical project demos and prototypes at the lab, which the teaching assistants made available, so she could feel the final, expected shapes. In addition to this haptic modality, Kulkarni reflected on how she enjoyed working on an audio-centric lab project, "I was excited to realize that my partner and I would be working on a music related project… [I] liked the project because it was audio-based. The final product must play music and light up differently based on the sound frequency."

Thus, to summarize, the inaccessibility of introductory ECE education required Kulkarni, the teaching team, the DSO, and the visual descriptionist to innovate and try different approaches to provide alternative, accessible representations of the course material, feedback, and project outputs. While some approaches worked better than others, this experimentation process was time-consuming and did not guarantee successful experiences.

4.1.3 Developing hands-on lab skills

ENGR 40M usually provides many students with their first exposure to ECE lab work. Kulkarni is one of those students, as she had not been in makerspaces or in ECE labs prior to this course. In fact, Kulkarni often described the course emphasis on making and lab work with excitement, especially when reflecting on the earlier, simpler lab projects of the course. She stated, "[I] *loved* that [ENGR 40M] gave [me] this area of beyond-software, more hands-on making… Even starting with the pre-lab [assignment], it was exciting to move away from the abstract."

Kulkarni was able to try some tools and explore components hands-on, though those opportunities became scarcer and more complicated as the quarter progressed and the lab projects incorporated more complexities. For instance, she "was able to feel the digital multimeter (DMM) and understand how current and voltage could be measured... [She] also participated in the set-up of the DMM and in sharing ideas, but [she] did not end up using the DMM on her own in the lab." In other scenarios, Kulkarni "was able to feel all the different components of the circuit that [she and her lab partner] were building and even understand in real time how it was being put together." However, at the same time, actions such as "screws and soldering work went over [her] head," as they were not as accessible to explore. Kulkarni added, "They offered for me to feel different parts [of the circuit]... I had confidence in finding the right components for the lab, but it got worse."

ENGR 40M also capitalizes on repetition and practice to improve students' comfort with certain lab skills. In particular, soldering is a skill that students utilize in every single lab throughout the course due to its importance to the field. Unfortunately, the soldering iron poses real danger if not held safely at its cold end. The students would need to visually inspect the applied solder to ensure that it has not overflown, and at the same time, that it sufficiently covered the connection area. Kulkarni "felt sad and frustrated about missing the useful [soldering] repetition" throughout the course. She also reflected on the importance of soldering exposure, as a missed opportunity for her, through her peers' experiences in a lab that requires students to solder tens of LEDs to build an LED cube. She stated, "To some, the immense amount of soldering in this lab is one of the most memorable components of the class, for better or for worse… With the LED array project, you're soldering repeatedly to learn the skill." As a result of such exclusion due to the ableist, primarily visual nature of lab tools, Kulkarni "focused much more heavily on concepts than labs, [and] it became much harder to solidify specific circuit [concepts] and tools that other students learned through making."

Even some components of the lab that Kulkarni thought would be inclusive, such as programming an Arduino, proved to be inaccessible. She explained, "The introduction of [the] Arduino further complicated the scene. The setup itself was not accessible, and once I got the IDE working, there was a one line offset with what JAWS read versus where my cursor was." Like many BLV learners, Kulkarni relied on a digital screen reader software, called JAWS, to convert her PC screen display from text to speech, so she could listen to the displayed information. However, the Arduino Integrated Development Environment (IDE) was not fully accessible to JAWS, and therefore, the latter was reading the code in the Arduino IDE with a one line offset, complicating Kulkarni's use of the IDE. She ended up dictating her code out loud to her visual descriptionist or lab partner, so they could type it in the inaccessible IDE. However, this backfired later in the course. During the final exam, Kulkarni was required to write Arduino code as an answer to a question, and given her prior approach of dictating the code out loud, she was not fully familiar with the expected code syntax. Thus, she had to write using a blend of pseudo code and some Arduino functions that she was familiar with.

As a result, while Kulkarni found some aspects of hands-on work in the lab to be fulfilling and exciting, there were many accessibility challenges that "redefined [her] entire course experience into just another theoretical course," forcing her to lose out on learning outcomes that other students were able to achieve via visual approaches.

4.1.4 Interactions with stakeholders

There were multiple stakeholders who were invested in improving Kulkarni's experience with the inherently inaccessible course. Kulkarni had regular contact and meetings with these individuals, and they contributed to different aspects of her course experience. Their titles and roles are briefly described in **Table 1**, and we elaborate on Kulkarni's interactions with these stakeholders throughout this section.

Table 1. The titles and brief role descriptions of multiple stakeholders who were involved in *Kulkarni's* experience in ENGR 40M.

Title	Role Description
Blind faculty mentor	Kulkarni's blind instructor in a prior computer science course. He also serves as a mentor to Kulkarni.
Course professor	The lead professor of ENGR 40M. He has extensive experience leading this course for over a decade and is invested in making engineering education more practical, fun, and accessible. He coordinated efforts with the disability services officer (DSO) and the rest of the teaching team to incorporate accessibility practices for Kulkarni's course experience.
Course and teaching assistant(s)	Undergraduate and master's students who are responsible for running office hours and leading lab sessions, among other tasks. They explored accessible learning methods with Kulkarni.
Disability services officer (DSO)	The accessibility manager at the disability services office at our academic institution. She created accessible, tactile diagrams for Kulkarni's course material and coordinated efforts with the course professor and teaching team.
Lab partner	A fellow student, enrolled in ENGR 40M, who partnered with Kulkarni during the lab sessions. This course requires students to work in pairs on lab projects.
Visual descriptionist	A student who had previously taken ENGR 40M and who was hired by the DSO to provide visual description to Kulkarni of the course content. The student met with Kulkarni during scheduled meeting hours outside of class and was present during lab sessions.

The visual descriptionist provided Kulkarni with a description of visual content, such as hardware components during the lab sessions, slides with images of circuit schematics during recorded lectures, and figures in homework assignments. The descriptionist also provided visual feedback on debugging efforts and assisted with drawing schematics that Kulkarni would verbally describe for homework submissions. The descriptionist attended the lab sessions with Kulkarni and met with her weekly outside of class. Kulkarni valued the descriptionist's various efforts, stating, "I think [my visual descriptionist] played a huge role in this positive experience. They offered for me to feel different [electronic] parts and were really patient with my questions."

Kulkarni also had a great relationship with her lab partner, as students worked in pairs during lab sessions. She recalled an instance during an advanced lab session where she felt fulfilled by the collaborative nature of the work, "During the LED display [project] lab, I wrote the entire code/program while my lab partner soldered the 64 LEDs. This divide-and-conquer experience was the first moment I felt that I fully contributed to the lab experience… We made this [task assignment] decision during the lab, as I already had a good working relationship with my lab partner." She reflected on her experience with her lab partner several times throughout the autoethnography process, stating, "I worked closely with my lab partner to write the code, and she validated that it worked as desired."

On the teaching side, Kulkarni had regular interactions with the course professor, who was the faculty lead, and the course instructors or teaching assistants, who were often students leading lab sections or revision sessions. Kulkarni had two scheduled meetings every week with a course instructor to clarify and elaborate on any inaccessible concepts and tools. The course professor and instructors experimented with different methods and approaches to figure out what worked best for Kulkarni, including hands-on exploration of what the completed project will be, assembling tactile cards into a circuit schematic, talking through the functionalities of different circuit components, and tracing circuits on a flat surface. Kulkarni appreciated the guidance and support that she received from the teaching team, stating, "[The team's support with making] made the end goal much more tangible… [The instructor talking through a concept] helped me "get it" and understand transistors [and other concepts] better."

On the institutional level, the disability services officer (DSO) worked with the course faculty shortly before the course on accessing the course material. Since the content relied on several hundreds of schematics, diagrams, and hands-on lab material, the officer worked with Kulkarni to decide on the type of materials of which to prioritize developing alternative, accessible formats.

The officer printed tactile cards of the schematic symbols of the most frequently used electronic components throughout the course. This allowed Kulkarni to use these modular elements to set up and explore some small circuit designs and to learn the schematics of associated components. Kulkarni elaborated on the role of the disability services office, explaining, "The [disability services office] is awesome… I want to emphasize that they truly helped, especially with the [tactile] cards and accessible formats of course material… But the [office] resources could only go too far and wouldn't have been able to figure out the [systemic] issues."

Apart from course-centric support, Kulkarni found the support of BLV faculty extremely valuable. She relied on her learnings from the experiences of a blind instructor, with whom she worked on adopting accessibility practices for a prior computer science course that she had taken, and she transferred that knowledge to this introductory ECE course. She shared, "[My instructor] in the Computer Science department, he's super good with accessibility… He just understands so much… I worked with him on making my [prior Computer Science course] accessible. It was very hard but a really good tooling experience… He was very helpful with setting up all my terminals and IDEs because he's a blind person himself."

To that point, Kulkarni acknowledged the importance of learning from lived BLV community experiences: "Ultimately, I was sure this [inaccessible hardware programming IDE] barrier had come up with other BLV people in the field, and I could have spent more time researching alternative strategies. However, given the approaching midterm and a lot of work for this class and others, it didn't seem worth it [to look into it further], especially because we were writing under ten lines of code."

This experience shed light on the type of frequent sacrifices that Kulkarni had to make to meet the pace of the course and the academic quarter in general, in parallel to the need for additional time to learn from the community experiences, which play a vital role in shaping the accessibility of fields such as introductory ECE education. Similarly, while working in the lab, Kulkarni made the decision to step back from hands-on exploration and learning several times. She reflected, "It became time to start soldering and buckle down on finishing, it was time for efficiency, and I naturally took a step back." Discussing another lab, she said, "I knew that any question or time it would take to feel a setup would slow us down."

In summary, Kulkarni greatly benefitted from many interactions with a diverse group of individuals who were invested in her success: the course teaching team, the DSO, the visual descriptionist, her lab partner, and a blind faculty member. Despite these positive experiences, Kulkarni still faced challenges, including time constraints and feeling like she had to carry the burden of looking for alternative, accessible approaches and methods at times.

4.1.5 Exploring and simplifying complex systems

As ENGR 40M progresses, students build enough foundational knowledge to be able to identify different electronic components, recognize their functionality, then analyze them as part of a larger circuit. Similarly, they should be able to tell what the overall objective of a circuit is and break it down into sub-circuits and components.

This experience, however, was not as easy for Kulkarni as it was for sighted students. She reflected on her ability to succeed at understanding circuit functionality, "Once [I] understood the pieces being talked about, it was easier for [me] to put everything together." However, she also shared, "Without understanding [some] concepts, I couldn't go through the process of putting all pieces together or synthesizing… In general, I could understand the individual components, and even subsets of the full circuit, but I struggled to remember how they all worked together. Recall was a big challenge after this lab was over, even if I talked it through enough [with an instructor] to make sense at the time." Some projects and circuit schematics included tens of components with different parallel and series wiring configurations. While such schematics can be explored and decomposed visually, retaining a mental map of those connections was hard for Kulkarni. Moreover, setting up a tactile design of these circuits was often resource-constrained by the limited number of tactile cards available and by the lack of accessible labeling of nodes and terminals.

Therefore, while Kulkarni was able to understand and explain sub-circuits as well as complete circuits during class and recall their details during the autoethnography process, the decomposition and synthesis processes of circuits was not as accessible as it was for sighted learners. Kulkarni stated, “Breaking down the project from one, big, assembled project to smaller subparts is not a luxury for a blind person.”

5 Discussion

5.1 A comparative analysis of the BLV and sighted learning experiences

The **Findings** section revealed five main CARE areas that provided Kulkarni with fulfilling experiences but also incorporated challenges simultaneously. It is obvious from the CARE areas of Kulkarni that most challenges she faced were rooted in accessibility issues and were the direct results of the ableism of introductory ECE education, in line with the definition of ableism that we previously provided in **Section 1.1.**

In fact, three of Kulkarni’s CARE areas overlap with those identified in the experiences of 42 sighted students who completed ENGR 40M in [53]. The overlapping and different CARE areas among the experiences of Kulkarni as a BLV student and those of sighted students are represented in **Table 2.**

Table 2. Distinct and overlapping CARE areas among the experiences of Kulkarni as a BLV learner in this work and sighted students in [53].

<table>
<tr><th colspan="3">CARE Areas</th></tr>
<tr><th>BLV Student Experiences Only</th><th>Overlapping Experiences of BLV and Sighted Students</th><th>Sighted Student Experiences Only</th></tr>
<tr><td>Experimental learning methods to improve accessibility</td><td>Understanding, analysis, and design of circuits</td><td>Debugging</td></tr>
<tr><td rowspan="2">Interactions with stakeholders</td><td>Developing hands-on lab skills</td><td rowspan="2">Working independently with room for innovation</td></tr>
<tr><td>Exploring and simplifying complex systems</td></tr>
</table>

It is important to highlight the difference in the BLV and sighted students' experiences under each of these CARE areas. In relation to the CARE area *"Understanding, analysis, and design of circuits,"* Kulkarni and multiple sighted students found the fundamental laws of transistors slightly confusing to grasp before fully understanding them as they were utilized in more practice problems throughout the course. However, most of the challenges that Kulkarni faced with exploring and analyzing electronic component behavior were traced back to the inaccessibility of the schematics of those components. Sighted students did not face those issues.

As for the CARE area *"Developing hands-on lab skills,"* the sighted students found soldering to be extremely difficult earlier in the course, but their perception of soldering transformed into a positive, rewarding experience a few labs later when they had to solder tens of LEDs. In contrast, Kulkarni did not get the chance to practice soldering and improve her skills to achieve fulfilling results. Instead, she considered the ability to merely participate in some hands-on lab activities a rewarding experience in itself.

Finally, while the title of the CARE area "Exploring and simplifying complex systems" seems identical on a high level, it pertains to different perceptions of synthesis and composition. Students in ENGR 40M were required to synthesize circuits using individual components and break down larger circuits into smaller sub-circuits. The students sometimes found such problems challenging because they had to figure out the intermediate steps on their own. Yet, they found it rewarding to be able to progress from the beginning point to arrive to a final, correct result. Kulkarni also struggled with these problems where she was required to break down a circuit into sub-circuits or utilize different components to build a circuit. However, her struggle stemmed from a different reason than that of sighted students, since she faced difficulties in retaining memory of the detailed connections and configurations of the many electronic circuit components that she chose to build a circuit. The mental map of a circuit of tens of components was challenging to preserve and retain.

Furthermore, an interesting comparison arises based on the *"Debugging"* CARE area of sighted students, which appeared in Kulkarni's data solely under "Challenging" experiences and not as a CARE area where "Challenging" and "Rewarding" experiences overlapped. In analyzing the data pertaining to the Debugging code further, it is evident that Kulkarni never got the chance to successfully complete the hardware debugging process to feel a sense of reward. The debugging process in ENGR 40M was inaccessible to Kulkarni, as it often relied on the use of hardware tools in the lab or on visual feedback. This prevented Kulkarni from debugging over iterations to resolve any bugs in the design. For instance, when she attempted to debug her code (which was supposed to light up a physical board with certain lights and colors), she had to wait for office hours with teaching assistants or for her meeting with her visual descriptionist to receive a verbal description of the results they saw on the physical board. This was a very time-consuming process and deprived Kulkarni from gaining an independent sense of achievement.

5.2 The impact of ableism in ECE on the BLV student's contextualized awareness of identity and emotions

When taking a closer look at the qualitative codes that represent data focused on emotions, Kulkarni has a larger and more diverse mix of codes representing emotions in comparison to those of the sighted students. Moreover, Kulkarni's emotion-centric codes are often rooted in her experiences with inaccessibility of the introductory ECE course.

The categorization structures that were adopted in the **Data Analysis** section included affective code areas, representing the human dimension and emotions as informed by Bloom's and Fink's taxonomies, and generated from Kulkarni's autoethnographic data. In the structure focused on rewarding experiences, three codes represented emotions (*excited, empowered, confident*). On the other hand, in the structure focused on challenging experiences, nine codes represented emotions; these codes included feeling *isolated, losing confidence, and feeling bored, confused, frustrated, intimidated, and unsatisfied*. It is also apparent that some codes in the two structures are opposite pairs; for instance, consider the pairs (confident, losing confidence) and (empowered, intimidated). These pairs reflect the mixed emotions that Kulkarni often came across during the course. Moreover, the larger number of emotion-centric codes pertaining to challenging experiences (nine) in comparison to those related to rewarding experiences (three) further emphasizes the effect of inaccessibility on Kulkarni.

Therefore, Kulkarni's autoethnography brought light to reflections on her identity as a blind engineer. For many students, this course is exciting because it moves away from traditional, textbook-styled learning into the space of hands-on exploration. Kulkarni was not immune to such excitement. Despite the extra accessibility considerations that her course experience required, Kulkarni expressed that this course *challenged* her to think in new ways and utilize her skill sets as a primarily tactile and spatial learner. She engaged heavily in understanding the concepts backing inaccessible visuals. As such, she was *confident* in her ability to discuss ECE concepts during lab sessions.

This positive energy was counteracted, however, by the exclusion that resulted from facing different realities about the feasibility of the course. One experience that Kulkarni identified as significantly *isolating* was when sighted peers were developing and practicing their hands-on skills, such as soldering and mechanical assembly. Kulkarni reflected on one such moment, "I sat beside my visual descriptionist who worked with my lab partner to get the box assembled. They voice-overed what they were doing, but I think this was the beginning of lab work not translating as directly with conceptual pre-lab work."

This reflection shows how inaccessibility can impose an acceptance of a power imbalance and a heightened awareness of one's disability. Kulkarni felt like she yielded to her sighted counterparts because she could not synthesize or participate in the same way. Furthermore, Kulkarni repeatedly used the term "sacrifice" in her journal entries, in reference to the experiences that she gave up to find measured success in the course, while not "hindering" other students' learning. This revealed an emotional loss of experiences that she felt she had to accept. Kulkarni also shared that she did not feel emotional about some of these challenges in the moment, and it was only when returning to these experiences retrospectively with a research lens that she started to question if it really had to be that way.

5.3 Recommendations to improve institutional and pedagogical support for BLV learners in ECE education

Based on the findings from this work, we propose a list of recommendations that could improve the experiences of BLV students in introductory ECE education. As these recommendations are sourced directly from Kulkarni's experiences, they are non-exhaustive. Therefore, the larger research community is invited to expand this list of recommendations, especially as more BLV experiences are given voice and amplified in future documentation efforts.

5.3.1 Recommendations to improve pedagogical support for BLV learners

Below, we provide recommendations that are tailored to BLV learning experiences in ECE educational contexts. These were extracted directly from the identified CARE areas in the **Findings** section and from qualitative codes that were categorized as pedagogy-centric in the CARE categorization structures (whether challenging or rewarding).

Accessible resources:

- As many introductory ECE courses rely on visual PowerPoint presentations to communicate ideas, educators must create accessible versions of those slides. That can be done by incorporating **alternative presentation formats**, such as adding and unifying alt-text to describe images or describing verbally the content of slides. For example, the educator can say, "On the screen, we can see a voltage source connected in series with a 100-Ohm resistor." Flipped classrooms, where instructors upload recordings of their presentations online, can be very helpful for BLV learners so they can pause the recording and explore their tactile resources simultaneously.
- Educators must pinpoint **universal labels** for all learners. For example, educators can guide learners to physical, tactile dividers on breadboards that can help the learner orient their way using a breadboard non-visually.

Learning experience support:

- Educators must **hold BLV learners to the same standards** and must plan for them to achieve the expected learning outcomes of the coursework. Therefore, educators need to explore accessible learning experiences, such as nonvisual soldering, and offer such opportunities to the students rather than eliminating such experiences because they are deemed inaccessible [29].
- Educators can dedicate short meeting times throughout the week to provide **visual feedback on visual debugging efforts** of BLV students (if nonvisual feedback is completely not possible). This could be done virtually or in person, with the intent of shortening the time needed to complete an iteration of the debugging process by the BLV learner.
- In designing collaborative learning experiences, it is important to factor in **interdependence** [65]. This notion maintains the collaborative role of all stakeholders involved in the success of the BLV student's learning process, excluding the need for complete dependence or complete independence to achieve the course objectives. For example, a lab project with a sonified output allows the BLV learner to collaborate with their lab partner in debugging their project outputs, providing the opportunity for the

BLV learner to use their auditory skills to influence the project design and the team/pair effort [66][67].

Accessible assessment:

- For assessment purposes, educators can **emphasize planned assessment metrics** that are taken for granted in the experience of sighted students. For example, a BLV student who often dictates code due to the inaccessibility of the coding platform will not practice code syntax regularly, and this will negatively impact their performance on the final exam when they are required to write their code as text input in the exam file.

5.3.2 Recommendations to improve institutional support for BLV learners

There are many individuals, offices, and programs at the institutional level that can create a more inclusive experience for BLV learners in ECE education, especially via partnerships among those entities. Some of the practices they can adopt are listed below.

University/College level:

- Academic institutions should invest in **creating sustainable, BLV-accessible ECE resources** with usage guides to facilitate the experience of future BLV learners and encourage them to pursue these now-accessible ECE courses.
- Disability-support programs and initiatives can connect BLV students with BLV mentors, especially faculty or staff who have the ECE knowledge required to successfully navigate the course under study. This can facilitate the exchange of **BLV lived experiences.**

Inter-program partnerships/alliances:

- The ECE teaching team should share course materials with the disability services officers (DSOs) in advance of the course start date, to provide the DSOs with enough time to **adapt the course material** into accessible formats.
- The DSOs should **share pointers on good practices** with the ECE teaching team, in case the teaching team members had not taught BLV students beforehand. Such pointers can include insight on utilizing tactile resources during office hours to answer the BLV student's questions.
- The DSOs and the teaching team should provide every session's material to the BLV student in advance. This way, the student has **enough time to familiarize themselves** with the resources, instead of exploring them for the first time during lectures or labs.
- Lab managers should collaborate with the DSOs to **test educational tools** before their adoption in coursework. For example, given that the Arduino IDE is not fully accessible using a digital screen reader, alternative development environments that are screen reader-friendly, such as Microsoft Visual Studio Code, can be recommended. This is an important approach to lift the burden of validating accessibility considerations off of the BLV student, given that sighted students do not carry this responsibility in the first place.

While such recommendations can help provide improved support for BLV learners, there are systemic barriers in ECE education that would need a more comprehensive transformation of the educational system as a whole. Moreover, there are many different or complementary approaches to facilitate more accessible ECE experiences. For example, we recently proposed a list of *design* considerations in [34] for more BLV-inclusive engineering education tools, and they are summarized in **Table A.1** in **Appendix A.** These design principles can apply to designing more BLV-accessible ECE curricula and resources. Furthermore, educational frameworks such as Universal Design for Learning (UDL) and SCAFFOLD promote inclusive teaching practices for students with a range of abilities and disabilities [68], [69]. While they are not ECE-centric or BLV-centric, many of their recommendations can be utilized to improve the accessibility of ECE education to BLV learners, and we adapted some of their principles in the recommendations that we provided, grounded in Kulkarni's experiences.

5.4 Expanding the CARE methodology to analyze inequitable challenges faced by learners with disabilities

We believe that this work illustrates how the CARE methodology can be utilized to document and explore the *inequitable* challenges faced by students with disabilities due to the inherent ableism of ECE education. The CARE methodology prioritizes the categorization of challenging and rewarding experiences, and it helps educators identify and assess *unproductive* challenges, which need to be mitigated, and *healthy* challenges, which contribute to the students' effective learning. In addition, this work was able to identify a third area of *inequitable* challenges that Kulkarni in particular faced due to the inaccessibility of the course material and resources; these were challenges that sighted students did not have to grapple with. This category of challenges is crucial to address by educators in their curricular design. As highlighted in **Section 5.2,** such experiences can worsen the student's learning experience through mixed emotions about their ability to succeed.

Consequently, using CARE to assess the experiences of students with disabilities can inform educators of inequitable challenges, in particular, that arise from the CARE assessment and from the students' perspectives, given that the CARE methodology centers student insights in the adopted data collection and analysis methods. This can inform curricular design alternatives that are inclusive of everyone and that can address and improve students' experiences directly. Moreover, we believe that the CARE methodology can help unveil the ableism of many engineering education fields, and not just ECE education.

5.5 Limitations and future work

The work presented in this paper is necessary to set the groundwork for a more inclusive transformation of introductory ECE education. That said, there are multiple areas of this work that can be improved.

First, this paper emphasizes the need for additional, expanded documentation of BLV experiences in ECE education, and this work does not attempt to generalize Kulkarni's experiences but rather considers them a launching point for the research community. However, it is important to note that a more balanced comparative analysis of BLV and sighted experiences in ECE education calls for including more BLV perspectives, rather than the approach we adopted which compared one BLV experience to 42 sighted experiences. Given the inaccessibility of ECE education, it is understandable that we were not able to invite an equal number of BLV students to participate, but we hope future studies take that into consideration.

Moreover, the research in [53] was conducted during the Summer 2022 academic quarter. Kulkarni had completed ENGR 40M in Spring 2022, before the plan for this work was proposed and implemented. While there are no significant curricular differences between the experiences over those two academic quarters, we are planning on studying the experiences of BLV and sighted students in the same environment in future work.

In addition, this work adopted post-facto journaling in the retrospective autoethnography process. This means that Kulkarni may have forgotten some experiences in the course and may have had memory lapses post-course completion. However, integrating autoethnography during the course could have had unintended consequences on Kulkarni's experience as a direct intervention, and it could have increased her awareness of certain experiences or influenced her behavior. Both approaches have advantages and disadvantages, and researchers adopting these methods should keep such consequences in mind.

Finally, the recommendations offered in this work were derived from the direct experiences of Kulkarni and the relevant CARE findings. However, these recommendations should be evaluated as interventions to provide evidence for their efficacy. We are planning on integrating these recommendations in a future study involving many BLV learners in an introductory ECE context.

6 Conclusion

In this work, we expanded our efforts focusing on the much-needed rigorous exploration and documentation of the experiences of students who are blind or have low-vision (BLV) in electrical and computer engineering (ECE) education. We collected autoethnographic data from the experiences of the first blind student to have completed the introductory ECE course, ENGR 40M, at Stanford University. We then utilized the CARE methodology to analyze the collected data, revealing five main experience areas that the student found simultaneously challenging and rewarding: 1) Understanding, analysis, and design of circuits, 2) Experimental learning methods for improved accessibility, 3) Developing hands-on lab skills, 4) Interactions with stakeholders, and 5) Exploring and simplifying complex systems. Based on the CARE area findings and the generated qualitative codes during data analysis, we provided a list of preliminary recommendations to improve pedagogical and institutional support for BLV learners in ECE education. While the CARE methodology was originally focused on uncovering *healthy* challenges, *unproductive* struggle, and *rewarding* experiences, we also demonstrated how the CARE assessment methodology can be expanded to identify *inequitable* challenges that students with disabilities face primarily due to the ableism of ECE education and engineering education fields more generally. We cross-compared the BLV student's experiences with those of sighted students who completed the same course to provide deeper insight on the discrepancy among the BLV and sighted experiences. Finally, we are planning on conducting more extensive studies to present affordances, including new frameworks and educational tools, that can improve the accessibility of ECE education to BLV learners. To achieve that, we strongly encourage the wider research community to join our efforts and ensure a more inclusive and welcoming engineering education environment to learners with disabilities.

Acknowledgements

The authors thank Dr. Lauren Aquino Shluzas, Professor Mark Horowitz, the ENGR 40M teaching team, the Office of Accessible Education team, and the Designing Education Lab members at Stanford University for their insight and support. Mouallem thank the Knight-Hennessy Scholars program for her graduate fellowship award. This work builds upon and deeply appreciates the prior efforts of BLV researchers and allies in the field.

References

[1] "Diversity and STEM: Women, Minorities, and Persons with Disabilities 2023," National Center for Science and Engineering Statistics (NCSES) Special Report. Available: https://ncses.nsf.gov/wmpd (accessed Jan. 29, 2024).

[2] E.M. Spingola, *"*Literature Review on Disability Participation in the Engineering Field*",* presented at the *2018 ASEE Annu. Conf. & Expo.,* Salt Lake City, Utah, USA, Jun. 2018, doi: 10.18260/1-2--30776

[3] M. V. Svyantek, "Missing from the Classroom: Current Representations of Disability in Engineering Education," presented at the *2016 ASEE Annu. Conf. & Expo.,* New Orleans, Louisiana, USA, Jun. 2016, doi: 10.18260/p.25728

[4] E. A. Cech, "*Engineering's Systemic Marginalization and Devaluation of Students and Professionals With Disabilities,*" presented at the *2021 ASEE Annu. Conf. & Expo.*, Virtual, Jul. 2021, URL: https://peer.asee.org/37080

[5] S. Lezotte, H. Hartman, S. Farrell, and T. R. Forin, "*Disability and Engineering: A Case of "Othering"?"* presented at the *2020* A*SEE Annu. Conf. & Expo.*, Virtual, Jun. 2020, doi: 10.18260/1-2--34467

[6] G. Bettencourt, E. Kimball, and R. S. Wells, "Disability in postsecondary STEM learning environments: What faculty focus groups reveal about definitions and obstacles to effective support," *Journal of Postsecondary Education and Disability,* vol. 31, no. 4, 2018, URL: https://scholarworks.umass.edu/cfssr_publishedwork/19

[7] C. Dunn, K. S. Rabren, S. L. Taylor, and C. K. Dotson, "Assisting students with high-incidence disabilities to pursue careers in science, technology, engineering, and mathematics," *Intervention in School and Clinic*, vol. 48, no. 1, pp. 47-54, 2012, doi: 10.1177/1053451212443151

[8] A. E. Slaton, "*Body? What Body? Considering Ability and Disability in STEM Disciplines," presented at the 2013* A*SEE Annu. Conf. & Expo*., Atlanta, Georgia, USA, Jun. 2013, doi: 10.18260/1-2--19261

[9] H. Jeannis, J. Joseph, M. Goldberg, K. Seelman, M. Schmeler, and R. A. Cooper, "Full-participation of students with physical disabilities in science and engineering

laboratories," *Disability and Rehabilitation: Assistive Technology,* vol. 13, no. 2, pp. 186-193, 2018, doi: 10.1080/17483107.2017.1300348

[10] C. McCall, A. Shew, D. R. Simmons, M. C. Paretti, and L. D. McNair, "Exploring student disability and professional identity: navigating sociocultural expectations in U.S. undergraduate civil engineering programs," *Australasian Journal of Engineering Education*, vol. 25, no. 1, pp. 79-89, 2020, doi: 10.1080/22054952.2020.1720434

[11] N. Mayat and S. L. Amosun, "Perceptions of Academic Staff towards Accommodating Students with Disabilities in a Civil Engineering Undergraduate Program in a University in South Africa," *Journal of Postsecondary Education and Disability,* vol. 24, no. 1, pp. 53-59, 2011.

[12] U. Quapp and K. Holschemacher, "Inclusive University Education by Special Examination Arrangements for Civil Engineering Students with Disabilities or Special Requirements," *2023 IEEE Global Engineering Education Conference (EDUCON)*, Kuwait, Kuwait, 2023, pp. 1-4, doi: 10.1109/EDUCON54358.2023.10125157.

[13] K. R. Bogart and D. S. Dunn, "Ableism special issue introduction," *Journal of Social Issues,* vol. 75, no. 3, pp. 650-664, 2019, doi: 10.1111/josi.12354

[14] T. Hehir, "Eliminating ableism in education," *Harvard educational review*, vol. 72, no. 1, pp. 1-33, 2002, doi: 10.17763/haer.72.1.03866528702g2105

[15] S. Furtney and C. Doyle, "*Work in Progress: Empowering students with disabilities through research involvement,"* paper presented at the *2022 ASEE Annu. Conf. & Expo*, Minneapolis, Minnesota, USA, Jun. 2022, URL: https://peer.asee.org/41798

[16] S. Nittala, S. Sheppard, and H. L. Chen, "Inclusive Course Design Checklist: A living document for faculty to create inclusive classrooms," paper presented at the *2023 ASEE Annu. Conf. & Expo,* Baltimore, Maryland, USA, Jun. 2023. URL: https://peer.asee.org/43622

[17] M. Arral, "10 Tips to Make Your Course More Accessible and Inclusive to Disabled Students," paper presented at the *2022 ASEE Annu. Conf. & Expo*, Minneapolis, Minnesota, USA, Jun. 2022.

[18] E. A. Cech, "Engineering ableism: The exclusion and devaluation of engineering students and professionals with physical disabilities and chronic and mental illness," *Journal of Engineering Education,* vol. 112, no. 2, pp. 462-487, 2023, doi: 10.1002/jee.20522

[19] G. W. Behm, R. S. Kushalnagar, J. S. Stanislow, and A. W. Kelst*one, "*Enhancing Accessibility of Engineering Lectures for Deaf & Hard of Hearing (DHH): Real-time Tracking Text Displays (RTTD) in Classrooms," paper presented at the *2015 ASEE Annu. Conf. & Expo*, Seattle, Washington, USA, Jun. 2015, doi: 10.18260/p.23995

[20] M. H. Leddy, “Technology to advance high school and undergraduate students with disabilities in science, technology, engineering, and mathematics,” *Journal of Special Education Technology,* vol. 25, no. 3, pp. 3-8, 2010, doi: 10.1177/016264341002500302

[21] S. Burgstahler, E. Moore, and L. Crawford. “AccessSTEM/AccessComputing/DO-IT Longitudinal Transition Study (ALTS).” University of Washington DO-IT. URL: https://www.washington.edu/doit/programs/accessstem/resources/accessstemdo-it-longitudinal-transition-study-alts/2010-report. (accessed Jan. 30, 2024).

[22] N. W. Moon, R. L. Todd, D. L. Morton, and E. Ivey, *Accommodating students with disabilities in science, technology, engineering, and mathematics (STEM),* Atlanta, Georgia, USA: Center for Assistive Technology and Environmental Access, Georgia Institute of Technology, 2012.

[23] W. Gordian-Velez, “Ensuring the inclusion of people with disabilities in STEM education and careers,” *Journal of Science Policy & Governance*, vol. 20, 2022, doi: 10.38126/JSPG200203

[24] H. H. Skilling, "Historical perspective for electrical engineering education," in *Proceedings of the IEEE*, vol. 59, no. 6, pp. 828-833, June 1971, doi: 10.1109/PROC.1971.8273.

[25] T. Luzuriaga, B. Benson and L. Thompson, "Work in Progress: Using Virtual Reality Technology for Remote Students and Students with Disabilities in an Electrical Engineering Lab," *2022 IEEE Frontiers in Education Conference (FIE),* Uppsala, Sweden, 2022, pp. 1-4, doi: 10.1109/FIE56618.2022.9962537.

[26] H. Senaratne, S. Ananthanarayan, and K. Ellis, “TronicBoards: An Accessible Electronics Toolkit for People with Intellectual Disabilities,” in *Proceedings of the 2022 CHI Conf. on Human Factors in Comp. Syst. (CHI '22),* New York, New York, USA, 2022, pp. 1-15, doi: 10.1145/3491102.3517483

[27] J. Seo, “Is the Maker Movement Inclusive of ANYONE?: Three Accessibility Considerations to Invite Blind Makers to the Making World,” *TechTrends*, vol. 63, pp. 514–520, 2019, doi: 10.1007/s11528-019-00377-3

[28] R. Chang, W. Wang, C. Chiang, T. Wu, Z. Xu, J. Luo, B. Chen, and X. Yang. 2021, “AccessibleCircuits: Adaptive Add-On Circuit Components for People with Blindness or Low Vision,” in *Proceedings of the 2021 CHI Conf. on Human Factors in Comp. Syst. (CHI '21),* New York, New York, USA, 2021, pp. 1–14, doi: 10.1145/3411764.3445690

[29] L. Race, J. A. Miele, C. Fleet, T. Igoe, and A. Hurst, “Putting Tools in Hands: Designing Curriculum for a Nonvisual Soldering Workshop,” in *Proceedings of the 22nd Int. ACM SIGACCESS Conf. on Comp. and Access. (ASSETS ’20),* New York, New York, USA, 2020, pp. 1–4, doi: 10.1145/3373625.3418011

[30] G. Sirokman, R. Barlow, A. Rodriguez, A. Clark, and L. Fogg, The use of 3D printed media to improve the accessibility of engineering educational materials," paper presented at the *2023 ASEE Annu. Conf. & Expo*, Baltimore, Maryland, USA, Jun. 2023.

[31] M. Aksela, "Towards Student-Centred Solutions and Pedagogical Innovations in Science Education through Co-Design Approach within Design-Based Research," *LUMAT: International Journal on Math, Science and Technology Education*, vol. *7,* no. 3, 2019, pp. 113-139.

[32] D. Higgins, A. Dennis, A. Stoddard, A. G. Maier, and S. Howitt, "'Power to empower': conceptions of teaching and learning in a pedagogical co-design partnership," *Higher Education Research & Development*, vol. 38, no. 6, 2019, pp. 1154-1167, doi: 10.1080/07294360.2019.1621270

[33] R. Sugino, S. Mizoguchi, K. Kimita, K. Muramatsu, T. Matsui, and Y. Shimomura, "A method for consensus building between teachers and learners in higher education through co-design process," in *Proceedings of the Intl. Conf. on Hum. Inter. and the Manag. of Info, Jun. 2016.*

[34] T. Kulkarni, G. Kim, and A. Mouallem, "A Case for Improving the Accessibility of Electrical and Computer Engineering Education – Starting with a Blind Student's Autoethnography," in Proceedings of the 25th Intl. ACM SIGACCESS Conf. on Comp. and Access. (ASSETS '23), New York, New York, USA, 2023, pp. 1-8, doi: 10.1145/3597638.3614551

[35] J. M. Case and G. Light, "Emerging research methodologies in engineering education research," *Journal of Engineering Education*, vol. 100, no. 1, 2011, pp. 186-210, doi: 10.1002/j.2168-9830.2011.tb00008.x

[36] M. L. Baba and D. Pawlowski, "Creating culture change: An ethnographic approach to the transformation of engineering education," *Int. Conf. on Eng. Ed*., Oslo, Norway, Aug. 2001.

[37] C. Brozina, A. Johri, B. Jesiek and R. Korte, "A Review of Digital Ethnographic Methods with Implications for Engineering Education Research," *2021 IEEE Front. in Ed. Conf. (FIE),* Lincoln, Nebraska, USA, 2021, pp. 1-6, doi: 10.1109/FIE49875.2021.9637057.

[38] M. Hammersley and P. Atkinson, *Ethnography: Principles in practice*, Routledge, 2019.

[39] C. Ellis and A. Bochner, "Autoethnography, personal narrative, reflexivity: Researcher as subject," in *Handbook of Qualitative Research,* 2nd ed., Sage Publications, 2000, pp. 733-768.

[40] R. B. Johnson, R. B., "Examining the validity structure of qualitative research," *Education*, vol. 118, no. 2, 1997, pp. 282-292.

[41] J. P. Martin and C. Garza, “Centering the marginalized student’s voice through autoethnography: Implications for engineering education research,” *Studies in Engineering Education*, vol. 1, no. 1, 2020.

[42] S. Marx, J. L. Pennington, and H. Chang,” Critical Autoethnography in Pursuit of Educational Equity: Introduction to the IJME Special Issue,” *International Journal of Multicultural Education*, vol. 19, no. 1, 2017, pp. 1-6, doi: 10.18251/ijme.v19i1.1393

[43] K. Pithouse-Morgan, D. Pillay, and I. Naicker, “Autoethnography as/in higher education,” in *Handbook of Autoethnography*, 2nd ed, New York, New York, Routledge, 2021.

[44] N. La Monica, “*Surviving or Thriving in Academia: Autoethnographic Accounts of Non-Visibly Disabled Grads' Experiences of Inclusion and Exclusion,”* Doctoral dissertation, Department of Geography and Earth Sciences, McMaster University,Ontario, Canada, 2016.

[45] D. Jain, V. Potluri, and A. Sharif, “Navigating Graduate School with a Disability,” in *Proceedings of the 22nd Int. ACM SIGACCESS Conf. on Comp. and Access. (ASSETS ’20),* New York, New York, USA, 2020, pp. 1–11, doi: 10.1145/3373625.3416986

[46] J. I. Charlton, *Nothing about us without us: Disability oppression and empowerment*, USA: University of California Press, 1998.

[47] R. K. Scotch, “ “Nothing About Us Without Us”: Disability Rights in America,” *OAH Magazine of History*, vol. 23, no. 3, Jul. 2009, pp. 17–22, doi: 10.1093/maghis/23.3.17

[48] A. Hogan, A., N.R. Jain, R. Peiris-John, and S. Ameratunga, “Disabled people say ‘Nothing about us without us’,” *The Clinical Teacher*, vol. 17, no. 1, 2020, pp. 70-75, doi: 10.1111/tct.13022

[49] J. Harvey, “Nothing about us without us! Utilising experiences of disability in higher education,” *The Journal of Inclusive Practice in Further and Higher Education*, vol. 11, no. 2, 2019, pp. 102-117.

[50] D. Martín-Alonso, E. Sierra, and N. Blanco, “Relationships and tensions between the curricular program and the lived curriculum. A narrative research,” *Teaching and teacher education*, vol. 105, 2021.

[51] P. Hatlen, “The core curriculum for blind and visually impaired students, including those with additional disabilities,” *RE: view*, vol. 28, no. 1, pp. 25-32, 1997.

[52] T. T. Aoki, W. F. Pinar, and R.L. Irwin, *Curriculum in a new key: The collected works of Ted T. Aoki*, Routledge, 2004.

[53] A. Mouallem, M. Horowitz, and S. Sheppard, “The CARE methodology: a new lens for introductory ECE course assessment based on student Challenging And Rewarding

Experiences," paper presented at the *2023 ASEE Annu. Conf. & Expo,* Baltimore, Maryland, USA, Jun. 2023. doi: 10.18260/1-2--44057

[54] A. Fritz, M. Horowitz, and A. Jha, "Online, Interactive Tool for Studying How Students Troubleshoot Circuits," paper presented at the *2021 ASEE Annu. Conf. & Expo,* Virtual, Jul. 2021, doi: 10.18260/1-2--37542

[55] S. Bell and M. Horowitz, "Rethinking non-major circuits pedagogy for improved motivation," paper presented at the *2018 ASEE Annu. Conf. & Expo,* Salt Lake City, Utah, USA, Jun. 2018, doi: 10.18260/1-2--30936

[56] K. Charmaz, "The grounded theory method: An explication and interpretation," *Contemporary field research*, pp. 109-126, 1983.

[57] A. Strauss and J. Corbin, "Grounded theory methodology: An overview," in Handbook of Qualitative Research, pp. 273-285, Sage Publications, 1994.

[58] R. M. Emerson, R. I. Fretz, and L. L. Shaw, "Processing fieldnotes: Coding and memoing, in Writing ethnographic fieldnotes, pp. 142-16, 1995.

[59] A. Strauss and J. Corbin. *Basics of qualitative research*. Sage publications, 1990.

[60] D. R. Krathwohl, "A revision of Bloom's taxonomy: An overview," *Theory into practice*, vol. 41, no. 4, pp. 212-218, 2002.

[61] L. D. Fink, *Creating significant learning experiences: An integrated approach to designing college courses*, John Wiley & Sons, 2013.

[62] O. Aishwarya, "Performing Qualitative Data Analysis as a Blind Researcher: Challenges, Workarounds and Design Recommendations," in *Proceedings of the 22nd Int. ACM SIGACCESS Conf. on Comp. and Access. (ASSETS '22),* Oct. 2022.

[63] L. J. Starr, "The use of autoethnography in educational research: Locating who we are in what we do," *Canadian Journal for New Scholars in Education*, vol. 3, no. 1, 2010.

[64] H. Wolcott, "On seeking-and rejecting-validity in qualitative research," *Qualitative inquiry in education: The continuing debate*, 1990.

[65] C. L. Bennett, E. Brady, and S. M. Branham, "Interdependence as a frame for assistive technology research and design," in *Proceedings of the 20th Int. ACM SIGACCESS Conf. on Comp. and Access. (ASSETS '18),* Galway, Ireland, Oct. 2018, doi: 10.1145/3234695.3236348

[66] R. Ramloll, W. Yu, S. Brewster, B. Riedel, M. Burton, and G. Dimigen, "Constructing sonified haptic line graphs for the blind student: first steps." In *Proceedings of the 4th Int. ACM SIGACCESS Conf. on Comp. and Access. (ASSETS '00),* New York, New York, USA, 2000, doi: 10.1145/354324.354330

[67] C. Limb and F. Bianco, “Sonification: The Use of Non-Speech Audio to Convey Information,” *Amer. Astro. Soc. Meet. Abs* vol. 55, no. 2, Jan. 2023.

[68] J. Seo, and G. T. Richard, “SCAFFOLDing all abilities into makerspaces: a design framework for universal, accessible and intersectionally inclusive making and learning,” *Information and Learning Sciences*, vol. *122*, pp. 795-815, 2021, doi: 10.1108/ILS-10-2020-0230

[69] D. Rose, “Universal design for learning,” *Journal of Special Education Technology*, vol. 15, no. 4, pp. 47-51, 2000.

Table A.1. Ten design considerations (presented in no particular order) to improve the accessibility of education technology for ECE educational contexts [34].

Design Consideration	The Tool Must…
Multimodality	Provide **multimodal** and/or tangible representations of information, such as sonifying real-time graphical outputs for debugging or providing tactile circuit schematics
Agency and room for support	Give the learner **agency** but allow them to ask for **help** as needed. It could allow the learner to debug their circuitry without the need for another person's description of outputs.
Fail-safe	Be **fail-safe**, allowing the learner to successfully recover from software or hardware errors, such as allowing the user to detect and replace a broken component.
Complex circuits exploration	**Support complex**, larger circuits by potentially integrating simpler representations for sub-circuits, to alleviate the mental load of remembering components within each sub-circuit.
Knowledge retention	Support the **retention** of the learner's mental model and knowledge of a circuit schematic. This enables the student to set up a circuit again for revision later.
Transferable learnings	Adopt **transferable learnings** from similar fields. Adopting the structural hierarchy of Python programming, a systematic circuit notation strategy can use indentation to distinguish electronic components connected in different configurations.
Accessible labels	Include **accessible labels** for all components, such as Braille labels for every terminal of an electronic component symbol on a tactile card and a card orientation marker.
Learning curve	**Not be time-consuming** to learn to use, in comparison to the adopted tools in class, because ECE education covers tens of tools that could significantly burden the learner.
Modularity	Be **modular** to allow the learner to alter and modify its set-up, such as changing connections and adding or removing components.
BLV lived experiences	The design process must be strongly grounded in the **lived experiences** of the BLV community. If such insights are not readily available, they must be sought, as we did.