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”Nothing About Us, Without Us”: Co-Designing an Accessible Engineering Education Tool with the Blind and Low Vision (BLV) Community

Aya Mouallem, Stanford University

Aya Mouallem (she/her) is a PhD candidate in Electrical Engineering 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 electrical engineering education to learners with disabilities. She is supported by the Knight-Hennessy Scholarship, the RAISE Fellowship, and the DARE Doctoral Fellowship.

Trini Rogando, Stanford University

Trini Rogando (she/her) is an undergraduate pursuing a B.S. Design in the Stanford University School of Engineering and Hasso Plattner Institute of Design. She is a research assistant in the Designing Education Lab at Stanford, with a focus on inclusive experiences.

Mr. Sean Patrick Dougherty M.S., LightHouse for the Blind and Visually Impaired

Sean Dougherty is currently leading the Social Enterprise team at LightHouse for the Blind and Visually Impaired, which includes mission-impact businesses such as Accessible User Experience (AUX), focused on usability testing of websites, apps & products along with supporting user research studies, and Media & Accessible Design (MAD) Lab, focused on printing & production of braille and tactile maps. Sean is a low vision user of assistive technology and is focused on developing partnerships with external organizations to support the BLV community through the LightHouse Social Enterprise businesses, including collaborations with large tech companies, startups, UX design agencies, and leading universities like Stanford, Berkeley, and Cornell to improve the accessibility/usability of current and future products/services. His previous work experience is in the Education Technology (EdTech) space, where he worked on the Google for Education team leading co-marketing partnerships with EdTech app developers who are building solutions for K-12 EDU & HigherEd classrooms, including accessibility-focused tools. He partnered with Google’s Accessibility team to drive awareness for first-party tools and accessibility features and supported accessibility app/hardware partners. Sean received his undergraduate degree in History/Liberal Arts from the University of Michigan in 2012 and his master’s degree in Assistive Technology & Human Services (ATHS) from California State University - Northridge (CSUN) in 2023.

Mirelys Mendez Pons, Stanford University

Mirelys Mendez Pons (she/her) is an undergraduate pursuing a B.S. in Product Design at the Stanford University School of Engineering and the Hasso Plattner Institute of Design, with a minor in Modern Languages and interdisciplinary honors in Education through the Graduate School of Education. She is a research assistant in the Designing Education Lab at Stanford, where her work focuses on accessibility in engineering education for blind and low-vision learners.

Dr. Sheri D. Sheppard, Stanford University

Sheri D. Sheppard, Ph.D., P.E., is professor emerita of Mechanical Engineering at Stanford University. Besides teaching both undergraduate and graduate design and education related classes at Stanford University, she conducts research on engineering education.

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Abstract

This paper is submitted under the "Intersection of Design and "X" Research Papers" category.

Electronics-based education is essential to different fields of engineering education, including electrical, mechanical, and biomedical engineering, as it equips students with technical skill sets to design, build, and test functional hardware devices. However, electronics-based engineering education remains largely inaccessible to learners who are blind or have low-vision (BLV), given its reliance on primarily visual tasks – from spatially sketching electronic circuits to visually analyzing digital simulation results. There have been limited but promising community efforts exploring the design of pedagogical and technology-based learning resources to create inclusive pathways to electronics-based engineering education for BLV learners.

To further expand these efforts, our research team co-designed the first BLV-accessible educational electronic circuit simulator, in collaboration with our community partner, LightHouse for the Blind and Visually Impaired, which supports the BLV community throughout California. Adopting the co-design method expanded the role of BLV participants to become active co-researchers with power to influence the research agenda and design directions. This work begins by reviewing the adopted co-design process, which spanned 2.5 years of iterative tool design, prototyping, and evaluation, where design principles from inclusive learning and design frameworks for an accessible tool design implementation, such as Universal Design for Learning (UDL) and ability-based design were adapted. We also discuss our data collection methods, in the form of surveys, observation notes, and reflection entries. We triangulate the perspectives and experiences of different stakeholders involved in this co-design process, including the BLV participants, the community partner, and the research team. After that, this work presents the findings resulting from the analysis of the collected data using the grounded theory building approach. The final stage of this work synthesizes the findings by proposing recommendations to support inclusive, community-based future efforts to co-design engineering education tools. Additionally, we present supplementary resources to support organizing and implementing these recommendations, and we discuss aligning the goals of co-design with liberatory design efforts.

1. Introduction

It has been 50 years since the Individuals with Disabilities Education Act (IDEA) was passed and amended in the United States [1], [2]. This law and its amendments ensured that students with disabilities would receive a free and public education in the least restrictive environment, and that all educational opportunities, activities, and facilities would be accessible to them as well. Since then, numerous educational entities and organizations have taken measures to ensure the accessibility of their educational offerings to learners of all types of visible and invisible disabilities. Among higher education entities is the Accreditation Board for Engineering and Technology (ABET), which accredits college and university programs in engineering and technology disciplines [3]. ABET established the Inclusion, Diversity, Equity, and Accessibility Advisory Council (IDEA Council), which reports directly to the Board of Directors and promotes commitment to its goals, including accessibility, via its accredited programs [4]. The American Society for Engineering Education (ASEE) similarly founded the Commission on Diversity, Equity, and Inclusion in 2009 as the main task force focused on improving diversity in engineering education [5], and accessibility to individuals with disabilities is among ASEE's commitments [6].

While higher-level policy and strategic plans have endorsed commitments to more inclusive engineering education for learners with disabilities, the real experiences of these learners often tell different stories of insufficient support and feelings of exclusion [7]. Studies have documented how learners with disabilities are often discouraged from pursuing engineering coursework in the first place [8]. Cech's reflexive, quantitative analysis of the ASEE survey data of 1,729 students found that engineering students with disabilities are less likely to experience social inclusion and more likely to intend to leave their engineering studies [9]. Moreover, students with mental and physical disabilities are more likely to report incidents of social marginalization and devaluation of professional capabilities [10]. Lezotte et al. explored the "otherness" experienced by students with disabilities and its impact on their sense of self-efficacy, belonging, and engagement in engineering [7].

In comparison to the growing bodies of research reporting the experiences of other minority groups in engineering, such as gender and race minorities, research pertaining to the experiences of people with disabilities remains relatively limited [10], [11]. Spingola reported a persisting gap in exploring the intersection of disability experiences and engineering education in ASEE proceedings [12]. Over the past decade, out of 53 ASEE papers nominated for and/or awarded the ASEE Best DEI Paper Award, only four papers focused on disability in engineering [13], [14], [15], [16], [17]. Svyantek conducted a literature review on representations of disability in ASEE publications and discussed the limited research exploring disability perceptions, accommodations, and inclusion efforts in engineering education [18].

Therefore, it is worth highlighting the research efforts that have explored disability experiences in different fields of engineering education. McCall et al. investigated the impact of sociocultural factors, including challenging and aligning with expectations, on the experiences of students with disabilities pursuing civil engineering studies [19]. Kulkarni et al. presented an autoethnographic study that identified different barriers faced by blind and low-vision learners in electrical engineering courses [20], and Mouallem et al. suggested good practices to improve pedagogical and institutional support for these learners [16]. Barlow et al. proposed new accessibility standards to textually describe graphics in mechanical engineering textbooks [15]. An ethnography study conducted by Hardin et al. revealed ableist assumptions in the pedagogical practices adopted when teaching design processes in biomedical engineering classrooms [21].

This work illustrates the power of co-design as a method for designing accessible engineering education tools *with* members of communities with disabilities, *for* these communities. In the next section, we review the relevant literature on designing accessible engineering education tools, inclusive design frameworks, and community-based design, including co-design, for disability inclusion. Then, we discuss the research aims of this work, which intend to answer the following research questions:

- Can co-design lead to creating more disability-inclusive engineering education resources?
- What are key strategies to integrate co-design in designing engineering education tools?
- How does co-design impact those involved in the design process?

2. Literature Review

2.1. Designing Disability-Inclusive Engineering Education Tools

To address the documented marginalization and exclusion experienced by students with disabilities, researchers have designed and studied the impact of several tools that could enable more accessible engineering education experiences. To support deaf and hard of hearing learners, Kushalnagar et al. incorporated the use of Real-Time Text Display (RTTD) in engineering labs, expanding its functions to support handling multiple speakers and identifying the location of the speaker [22], [23]. Such features allowed for alternative, real-time access to verbal and spoken information, to support the inclusion of deaf and hard of hearing engineering students. Seo and Rogge presented new features, co-designed by sighted and blind developers, to improve the accessibility of Visual Studio Code (VSCode) to blind users; VSCode is a popular software development environment in software and computer engineering classes [24]. To support learners with intellectual disabilities, Senaratne et al. designed TronicBoards, an electronics toolkit which emphasizes easily graspable and manipulable components with visual and tactile cues for improved accessibility in learning electronic circuit design [25].

Inclusive design frameworks can support researchers in integrating accessibility-centric features into their engineering education tool designs. The Universal Design for Learning (UDL) framework aims to improve the learning experience for all people [26]. To support the experiences of learners with disabilities, UDL encourages the representation and perception of data in different ways, which can entail multimodal data formats, and it recommends design compatible with assistive technology [27]. The Web Content Accessibility Guidelines (WCAG) also serve as standard reference for the accessible development of digital tools and content [28].

Wobbrock et al. developed the ability-based design framework, which "attempts to shift the focus of accessible design from disability to ability" [29]. Thus, the tool design must adapt to the abilities of the learner, and the ability-based design framework outlines several principles to support that aim [30].

2.2. Community-Based Design for Disability Inclusion

Designing for learners with disabilities draws upon the principles of design justice, which advocate for centering the voices of those who are most marginalized. These principles view change as accessible and collaborative and emphasize that everyone is an expert based on their own lived experiences. Design justice works towards community-led and controlled outcomes [31]. On a similar note, liberatory design calls for transforming the power dynamics by giving the communities that were most marginalized by existing design systems more agency, influence, and room for meaningful participation in the design process [32]. These frameworks center and actively involve learners with disabilities in the design process, aligning with the slogan "Nothing about us, without us," which disability advocates had adopted for decades [33].

A common thread among such frameworks is offering room for community-based collaboration in design. In fact, the co-design framework amplifies the role of community members as co-designers with power to influence the design directions and main, defining features. Accordingly, co-design shifts the balance of power between community members and designers — in essence, designing "with, not for, people" [34]. Furthermore, by emphasizing the understanding of one's individual positionality and implicit biases throughout the co-design process, the latter can become a medium for co-designing equitably with marginalized groups, including communities with disabilities.

In fact, the co-design process has been adopted in several projects designing for disability inclusion. For example, Metatla et al. adopted the co-design process with blind, low-vision, and sighted students to develop an inclusive and accessible educational game [35]. Winters et al. discussed the co-design of an interactive, accessible science education simulation by blind and low-vision high school students with researchers [36]. Adler et al., over three workshops, co-designed a mobile health app with cancer survivors with disabilities to improve the latter's ability to manage cancer as a chronic condition with an improved quality of life [37]. In addition, Seita et al. conducted online co-design workshops with deaf and hard of hearing individuals regarding features of communication applications. In line with the success of such a range of projects adopting co-design for disability inclusion, co-design can be adopted to improve the accessibility of engineering education, as demonstrated by a relatively small but promising body of literature in the ASEE community [38], [39], [40], [41].

3. Research Aims

Our research team is leading a comprehensive effort to investigate and improve the accessibility of electrical engineering education to learners with disabilities. In this work, following our positionality statement, we review the 2.5-year long program that brought together the blind and low-vision (BLV) community in the San Francisco Bay Area with blind and sighted researchers at Stanford University to co-design, prototype, and evaluate the first BLV-accessible educational electronic circuit simulator. The program, called Research on Accessible Design (RAD), involved multiple *design partners,* or *co-designers*: BLV community members in the San Francisco Bay Area, leadership of LightHouse for the Blind and Visually Impaired, which is a leading non-profit that serves the BLV community in the area and the main community partner for this work, in addition to blind and sighted researchers. Next, we analyze the reflections and insights that were shared by the participants and researchers throughout the co-design process via surveys, observation notes, and written reflection entries. Based on the analysis results, we discuss our aforementioned research questions. Finally, we present a set of recommendations to support the inclusive, community-based co-design of future engineering education tools.

4. Positionality

The authors of this work come from different areas of expertise and have had diverse lived experiences that relate to several aspects of this work.

Mouallem is a sighted graduate student at Stanford University, formally trained in Electrical Engineering, and conducting research on the accessibility of engineering education to learners with disabilities. Rogando and Mendez Pons are sighted undergraduate students in the Design program at Stanford and have conducted research on accessible practices in design. Dougherty is a low-vision, senior director at LightHouse for the Blind and Visually Impaired, and he has prior work experience in the education technology industry. Finally, Sheppard is faculty at Stanford University and has taught blind students in her Mechanical Engineering courses.

Mouallem, Rogando, and Mendez Pons organized and co-led the co-design program discussed in this work. They also developed the curricular resources, supported by the University's disability services office. Mouallem and Dougherty established a community partnership between the research team on the University's end and the non-profit. Sheppard advised Mouallem, Rogando, and Mendez Pons on qualitative research and design methods.

Dougherty led the outreach efforts via LightHouse to invite BLV community members to participate in the co-design process. Eight blind or low-vision individuals joined the effort, and they had diverse lived experiences with disability. The participants had different prior levels of exposure to electronics, making, and design; however, they all shared an interest in supporting research efforts to improve the accessibility of engineering education. The identities of the participants are anonymized in accordance with the approved Institutional Review Board (IRB) protocol for this work.

5. Overview of the Research on Accessible Design (RAD) Program

The Research on Accessible Design (RAD) program was organized at Stanford University to foster collaborations among researchers and the BLV community in co-designing BLV-accessible learning experiences and technology tools for engineering education. Figure 1 provides an overview of the RAD program timeline. Of note is that the findings presented later in this work are primarily outcomes of *Stage 5* in the timeline presented. This stage entailed the implementation of the RAD 1.0 and RAD 2.0 programming.

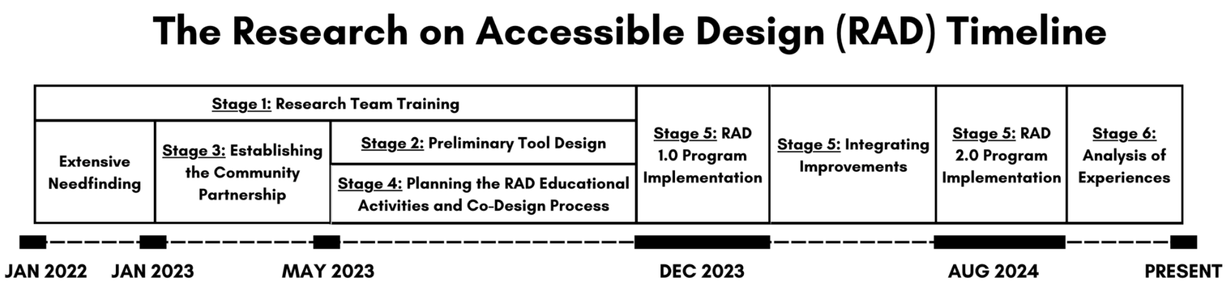

Figure 1. The Research on Accessible Design (RAD) program timeline.

Stage 1: Research Team Training (Jan 2022 – Nov 2023)

Our research team at Stanford University, which included blind and sighted researchers, completed different forms of training in preparation for organizing the RAD program. Sighted researchers learned to use digital screen readers, such as MacOS VoiceOver, in order to collaborate efficiently with BLV community members who would join the project as co-designers – many of whom primarily relied on screen readers to use digital tools. Moreover, blind and sighted researchers completed accessibility courses on accessible user experience design, such as the Web Content Accessibility Guidelines (WCAG) framework. Blind researchers on the team provided further advice and guidance based on their lived experiences and expertise in using assistive technology. Furthermore, blind and sighted researchers completed qualitative research training, covering methods such as autoethnography and qualitative data coding. Mouallem, the lead project researcher, also completed a community-based research training fellowship. Researchers completed training sessions on working with the BLV community and sought feedback from LightHouse on good practices to keep in mind. All researchers completed the human subject research training required for IRB approval.

Stage 2: Preliminary Tool Design (May 2023 – Nov 2023)

Prior works conducted by the research team identified inaccessible areas of electrical engineering education to BLV learners [16], [20]. Electronic circuit simulation was flagged as particularly inaccessible due to its reliance on visual tasks. To simulate a circuit, especially in introductory electrical engineering courses, a learner would have to drag and drop electronic component symbols on the screen, draw wires to connect the components using the cursor, and spatially navigate the circuit design to specify simulation targets. The outputs would often entail colored graphs and plots. Therefore, the Stanford research team decided to design, develop, and evaluate the first BLV-accessible electronic circuit simulator in collaboration with the wider BLV community. The co-designed and improved tool would be available as a free, open-source tool.

The researchers first built a preliminary prototype to serve as the foundation for all upcoming co-design efforts with BLV community members. RAD digital materials, shared with BLV participants, made it clear that this preliminary prototype was only a "scrappy medium" to start co-designing, and their input would be crucial in transforming and improving this prototype into an accessible and usable interactive tool.

Blind researchers prototyped preliminary hardware designs and collaborated on digital tool design and testing. Sighted researchers manufactured the hardware tool elements at a makerspace on campus and completed different software development tasks.

Next, we provide a brief overview of the tool design and expected use scenario in this section, and our work in [42] discusses in detail the accessible design of the tool.

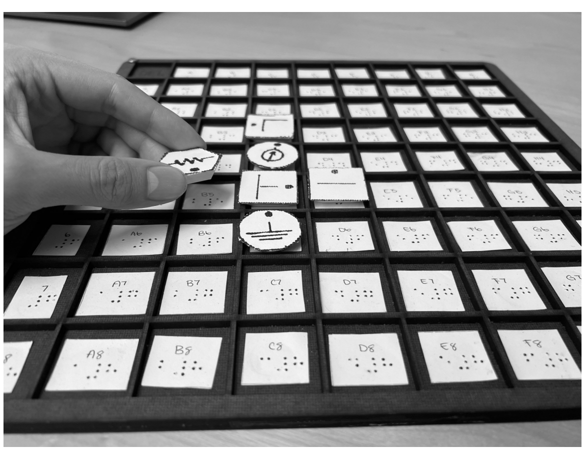

Figure 2. A user carries a tile representing a resistor above the hardware grid.

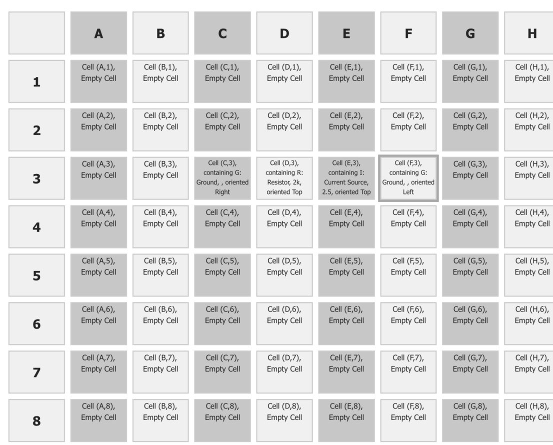

Figure 3. The digital grid displays cells with defined components.

This preliminary prototype consisted of several hardware and digital elements. The hardware included 3D-printed, braille-labeled tactile hardware blocks representing different electronic components, and a braille-labeled and audio-supported hardware grid. The digital simulation app, accessible by a screen reader, included a digital representation of the grid, and the user could define and save electronic components in every cell of the grid. The digital app could then simulate the circuit design and present its nonvisual results in an accessible manner. Figures 2 and 3 show the preliminary software-digital tool design. A user would be able to design and simulate a circuit using the preliminary prototype as follows:

1. The user can explore the available hardware blocks and select those with tactile schematic symbols of the needed electronic components.
2. The user can place these blocks on the hardware grid in different orientations to set up the planned circuit design.
3. The user then inputs their hardware circuit design into the digital grid of the simulator app, using the keyboard to navigate the digital grid and save the electronic components in different cells. They can define the type, orientation, and value of each component.
4. Once completed, the digital circuit design can be simulated. The user can use a keyboard shortcut to call and complete the simulation profile. They can choose the type of simulation and the component across/for which they would generate simulation results.
5. The simulator app would print out the simulation results. These include numerical results, warning messages, error messages, and hints or reminders to debug successfully.
6. The user can then iterate to fix errors, if any, by going through the hardware-digital design and simulation process.

Stage 3: Establishing the Community Partnership (Jan 2023 – May 2023)

The accessibility research mentor of Mouallem connected her to LightHouse for the Blind and Visually Impaired, a leading non-profit that serves the BLV community in the San Francisco Bay Area and aims to foster independence and equity in community for BLV individuals. The non-profit runs numerous initiatives and programs to engage the BLV community of all ages in accessible experiences, such as leadership and self-advocacy development for teenagers, tactile-centered activities for young learners, and accessible media design production. Mouallem reached out to LightHouse proposing a community partnership via the RAD program, and she held multiple conversations with different leaders at the non-profit to refine and align the goals of the RAD program with the mission of LightHouse.

A few months into the conversations, a director at LightHouse connected Mouallem to Dougherty, who currently directs accessible user experience projects at the non-profit. Mouallem and the LightHouse team, including Dougherty, then iterated on drafting a Memorandum of Understanding (MOU). The MOU covered the purpose and the scope of the project, its anticipated outcomes, ethical considerations, deliverables, dissemination plan, evaluation steps, timeline, and budget. Next, the MOU was expanded to discuss the shared goals of the project for both the Stanford research team and LightHouse, the resulting benefits from the project for both entities, a plan for exchanging and sharing resources and expertise, and a timeline of the involvement of each entity and their responsibilities at every stage of the project. The Stanford research team and the LightHouse team dedicated sufficient time over six months to build rapport and carefully design a partnership that aligned well with the mission and goals of each entity and that could maximize benefit for the BLV community and the research community.

Stage 4: Planning the RAD Educational Activities and Co-Design Process (May 2023 – Nov 2023)

The research team and LightHouse envisioned different real-life educational sessions and activities during the RAD program to introduce RAD participants to foundational electrical engineering concepts and to complete such activities using the co-designed accessible electronic circuit simulator. The researchers led the pedagogy design efforts, and they developed several resources, discussed below, to support the RAD educational experiences. The researchers filled in the LightHouse team on the design and development of these resources, and the LightHouse team offered advice for improvement where needed. These resources were designed in line with the WCAG framework and tested for accessibility prior to RAD.

- *Electrical engineering refresher document:* While participants were expected to have a basic, high-school level understanding of electronics, the researchers prepared a digital refresher document to ensure that all participants joined the RAD program on equal footing. The document covered foundational concepts, such as voltage and current, introductory circuit concepts, such as series and parallel circuits, as well as a description of the main electronic components that would be used during RAD, such as resistors and power sources. Moreover, researchers included brief guidance on main steps and tasks that are completed during circuit design, such as debugging. Participants were asked to review this document before the in-person RAD program, and they had to answer questions based on this document's content in their participation confirmation form. This counted as a revision checkpoint and ensured participants carefully reviewed the content before the program.

- *Activity workbook:* The researchers prepared an extensive digital activity workbook to guide the participants during the RAD program. The workbook covered different activities. For each activity, a brief list of reminders was included on tool use, concepts to keep in mind, and ways to participate in research (e.g., use the think-aloud method). Each activity was divided into steps, and participants could type in their answers and thoughts under each step. Appendix A includes the complete activity workbook of RAD 2.0.

- *Tool use guide:* This guide introduced the participants to the different features of the accessible simulator tool. It included a list of the shortcuts that could be used and relevant examples. During RAD, participants, in their capacities as co-designers, decided to integrate a tutorial into the simulator tool, in lieu of this tool use guide. Thus, the researchers developed an in-app tutorial that introduced the tool features and shortcuts instead, via an interactive simulation activity.

In addition, the research team designed the in-person schedule of the RAD program, which entailed the previously mentioned electrical engineering activities included in the activity workbook, in addition to individual and group-based design exercises, such as an introductory session on design thinking and a co-design reflection session, both of which were facilitated by blind and sighted researchers.

Stage 5: RAD Program Implementation

RAD entailed two in-person programs and one virtual workshop. For detailed information on the different types of activities completed during RAD, Appendix A presents the complete activity workbook for RAD 2.0, including activities on circuit design, a real-life engineering scenario, and co-design reflection activities. Appendix B includes RAD organizing resources.

<u>RAD 1.0 (Dec 2023)</u>

Eight BLV participants joined the first RAD program, RAD 1.0, in person on the Stanford campus. This program used the preliminary tool prototype, described in *Stage 2*, as a scrappy foundation upon which the co-design efforts would build. The BLV community members first completed a set of electrical engineering activities using the tool. These activities included designing circuits in certain configurations and debugging an erroneous circuit design. The participants also completed **design thinking exercises.** Later, during the **co-design reflection** session, they critiqued the preliminary prototype, proposed design recommendations, and made design decisions informing the next iteration of the tool design. These decisions included incorporating white-black color contrast in the hardware tool design for low-vision users, adding an in-app tutorial for the digital simulator, and reducing the hardware size. Moreover, RAD 1.0 included a lunch panel discussion with BLV scientists and technology professionals about inclusive STEM education for BLV learners. After the day ended, participants were asked to complete a post-program survey about their experiences.

<u>Integrating Design Changes (Jan 2023 – Jul 2024)</u>

The research team integrated the aforementioned design changes and recommendations of the participants into the tool design in preparation for RAD 2.0. Researchers primarily relied on makerspace tools, such as laser cutters and 3D printers, to prototype the improved tool design.

Pre-RAD 2.0 Virtual Workshop (Aug 2024)

The research team led virtual workshop sessions prior to RAD 2.0 with three returning participants from RAD 1.0 who indicated interest in participating in future sessions and were available during the proposed dates. The virtual workshops entailed a revision of electrical engineering concepts, an overview of the integrated design improvements, a discussion of potential dissemination avenues for the tool, and an extensive tutorial walkthrough. Furthermore, during onboarding for RAD 2.0, participants created a collective community guidelines document, where they proposed practices to facilitate supportive, kind, and inclusive co-design, and they adopted these practices during the in-person RAD programming.

RAD 2.0 (Aug 2024)

This was the second in-person RAD program organized on campus. The three returning participants engaged in a set of educational activities using the improved simulator tool. These activities included new, real-life scenarios such as fixing a broken electric heater circuit. The participants ended the day with another co-design reflection session, during which they discussed the integrated improvements, reflected on their co-design experiences, and explored next steps. Finally, participants were asked to complete a post-program survey about their experiences, while researchers were asked to write reflection entries in response to guided prompts about their experiences with the co-design process.

Stage 6: Analysis of Experiences (Sep 2024 – Present)

After wrapping up on the RAD programming, the researchers worked collaboratively to analyze the rich data collected throughout the RAD 1.0 and RAD 2.0 programs. The data provided insight on the accessibility, learning, and co-design aspects of the program. In this work, we focus on the co-design process.

6. Methods

6.1. Data Collection

BLV participants were asked to complete final program surveys after RAD 1.0 and 2.0. These surveys included open-ended and closed-ended questions about the participants' experiences in terms of the tool's accessibility, learning and educational outcomes, and the co-design stages and activities. During the program, researchers took observation notes and recorded important points from ongoing discussions and verbal feedback. In addition to data collected from participants, the co-authors on this work wrote two pages of responses to guided reflection prompts, post-RAD 2.0, which were personalized based on each co-author's role in the RAD program. These prompts asked about the co-authors' experiences with facilitating the program, any uncovered assumptions, impressions of the tool's design evolution, and role in the co-design process.

6.2. Data Analysis

We adopted the grounded theory approach, through which findings directly emerged from the collected qualitative data [43], [44]. We first coded the RAD 2.0 participant survey data inductively, and we started with a round of open coding, generating as many codes as possible. Then, with a round of focused coding, we refined the generated codebook, modifying, merging, and connecting codes where possible [45]. The final codebook included 57 codes clustered under 13 themes. Examples of the themes included Identity and Lived Experiences, Tool Features, and Design Recommendations. After that, we coded the researchers' reflection entries deductively, using the codebook generated from coding the participant data. The final codebook included 15 themes, including new themes such as Community Partnership, and the number of codes rose to 86 codes. In the following sections, we refer to researchers as R[number] and participants as P[number] to preserve anonymity.

6.3. Validity and Research Quality

We employed validity strategies to improve the research quality of our work [46], [47]. We adopted data triangulation by collecting and analyzing data from participants and researchers, representing different perspectives regarding the same co-design process. Moreover, we adopted investigator triangulation, as Mouallem and Rogando worked collaboratively on analyzing the survey and reflection data, meeting regularly to discuss the codebook development process and unifying codebook modifications.

7. Findings

In this section, we expand on multiple themes relevant to co-design from the codebook. We focus on feedback from the three participants who completed both RAD 1.0 and RAD 2.0.

7.1. Collaboration and Shared Tool Experiences

The RAD program entailed collaborative use of the simulator tool to complete pair activities, in addition to individual sessions. Each iteration of the program culminated in a group co-design reflection session to share experiences with the tool and recommendations for improvement. According to **P6**, collaboration was possible as *"accessibility [was] not the impediment, and instead, the educational/engineering content [was] the focus of the collaboration."* **P1** noted how they and their partner had *"synergetic collaboration that embraced both [their] talents equally, with both of [them] grateful to the other"* while completing a pair activity. Participants drew connections between such collaboration and the co-design process, stating that *"the co-*

design process emphasized both the interconnectivity and uniqueness of the whole [process]" among the participants, and that *"hearing other user experiences really helped [them] understand [their] own struggles and triumphs."* As a result, collaboration using the tool and during the co-design reflection session brought to light diverse and shared individual and group experiences with the tool, which informed collective recommendations for improvement.

7.2. Recommendations for Tool Design Improvement

During the co-design reflection sessions and in their final survey responses, BLV participants proposed recommendations to further improve the tool design. Participants synergistically bounced off of each other's ideas to come up with group recommendations, and researchers took observation notes of such interactions. Sometimes, one participant would bring up an issue with the tool and others would support the point made. For example, while participants initially did not have concerns about the shape and size of the hardware tiles, a participant mentioned their concern about the tiles easily sliding within their cells. Other participants took a minute to think and agreed that a unified square design for all components could avoid unintentional tile rotation or movement. In other cases, participants had different opinions but came to a conclusion to move forward with the co-design process. While one low-vision participant enjoyed the current scheme of color contrast for the hardware (white background, black lining for the raised schematics), another low-vision participant discussed their preference for a flipped scheme (black background, white lining). The participants discussed this point further and decided to flip the color scheme, as the former participant did not mind that, while the latter participant explained how it could significantly improve their experience. Additional feedback from the LightHouse team noted more universal benefits resulting from the availability of a "dark mode," as this could benefit low vision users who are sensitive to light and sighted users, too, who experience eye fatigue due to screen use over longer periods of time.

Finally, BLV participants brought in new knowledge and learned about new resources, skills, and experiences via the reflections of fellow participants. As a collective, they were also able to provide an array of diverse recommendations, from programming to tactile design. For instance, **P1** had prior experience with tactile art design, so they proposed the use of bold heat embossing to create *"bolder"* schematics on the hardware tiles. **P10**, on the other hand, focused on recommendations to smoothen the software user experience, such as disabling redundant Tab clicks while using a digital screen reader. Overall, the co-design process allowed participants to provide abundant and critical feedback for improvement, and **P6** shared that the program schedule and content *"[gave] ample opportunities to surface [these issues]."*

7.3. Centering Accessibility and Lived Experiences

Participants and researchers had very different lived experiences prior to joining RAD. The research team included sighted and blind researchers. Participants were blind or had low vision, and some had lost their vision later in life, while others were born blind. Participants' exposure to STEM and design also varied. **P6** referred to his *"past experience with engineering work"* as he discussed software improvements, while **P1** highlighted her *"interest in accessible and inclusive design."* Different participants relied on different accessibility tools and assistive technology. **P10** said their *"favorite feature [was] keyboard-only operation,"* while **P1** relied on magnification. Thus, as co-designers, participants had to navigate their different preferences, compare their experiences, and work together to improve the tool in a manner that is accessible and inclusive to all. Of note is that participants unanimously gave a full (5 out of 5) rating on the survey item: *"I feel that my opinions were heard, and my perspectives were valued by participants and researchers,"* which signified the responsiveness of the co-design process to participants' different lived experiences with disability.

By being exposed to others' experiences, participants began to think of design improvements to serve others in the community. For instance, **P1**, who has low vision, relied on magnification for digital navigation of content resources, but they reflected on nuanced experiences of other low-vision users, sharing, *"I'm thinking of those with low vision who don't necessarily need magnification but need larger font for ease of reading."* Furthermore, co-design gave all participants power to influence the accessibility of the tool and to contribute to improving inclusive engineering education. **P6** stated that co-design *"increased [their] ownership and stake in the success of the tool to make circuit design and learning more accessible."*

In addition to co-design enabling participants to improve the accessibility of the tool, researchers ensured that the co-design process itself would be accessible and inclusive to the BLV participants. **R2** reflected on the high-level vision behind the program and its goals, *"Creating an accessible tool is not enough, this effort should be accompanied by designing accessible and inclusive pedagogy, training educators, and engaging with other entities that contribute to the learner's success, too."* **R3** shared that *"[they] wanted to prioritize accessibility and inclusivity, not only in the… expectations of the activities we were doing, but also in creating a comfortable environment for the participants to share their thoughts."* As a result, the RAD curricular content offered an inclusive space for all participants to contribute to different aspects of the tool design, an approach that **P1** described as attracting *"creative"* and *"mathematical"* mindsets, and the co-design material were available in screen reader-friendly digital formats and/or as tactile printouts.

Researchers primarily served as facilitators, ensuring that the program ran on time and that participants were enjoying the program. **R3** discussed how she facilitated activities *"such as the [improvisation] stoke [to] solely to create a sense of community and acceptance in the room."* **R2** assigned *"4x the time estimated"* for activities during RAD 2.0, and *"from what [they] observed, RAD 2.0 was smoother, more comfortable, and better supported."* Beyond that, participants took the reins as co-designers to produce valuable findings and knowledge, motivated by their lived experiences and interests. **R1** highlighted that *"[the participants] truly understand what they need, and their feedback helps refine and validate the design,"* and **R5** reflected, *"I think it was a good reminder that any tool you give someone can be used in multiple ways, and there's not necessarily a right way,"* adding that *"it's [the participants'] world, and they came to the table really wanting to talk about that world and have others understand it, just from human to human."* Therefore, by ensuring the accessibility of the co-design process itself, the researchers created a supportive infrastructure for the participants to experiment and innovate.

7.4. Community Partnership

The community partnership involved the BLV community in different stages of the co-design process, due to certain steps taken by the researchers and the nonprofit leads to ensure a productive, positive, and successful partnership. **Mouallem** recalled reaching out LightHouse *"via a connection that [her] accessibility research mentor offered,"* as her mentor had collaborated with and was trusted by the nonprofit. **Dougherty** described how *"**Mouallem** re-engaged LightHouse through multiple conversations with the [nonprofit] leadership and got executive buy-in through stakeholders at the VP-level."* Soon after, **Mouallem** and **Dougherty** were connected, and **Mouallem** met with *"**Dougherty** [and] other LightHouse team members… multiple times to go over [her] project proposal and their reactions… [iterating] on reviewing it… to agree on the final version."* **Dougherty**, in turn, commended this approach by stating how important it is to *"lean on the community partner to help engage and connect with the community of interest,"* by establishing a *"primary contact from the community-partner org and [involving] the community partner throughout the research process."*

Throughout this process, the research team and nonprofit leadership built sufficient trust to lead a long community partnership by identifying and establishing common goals. **Mouallem** said she found **Dougherty's** expertise and focus to be *"aligned with [her] community-based project plan"* and recalled how the LightHouse team *"emphasized their interest in supporting STEM programming for the BLV community."* **Dougherty** confirmed these goals by reiterating the importance of *"being able to be involved in foundational research at the earliest stages to help make the Electrical Engineering field more accessible to the BLV community."*

The research and nonprofit entities discussed and coordinated *"community engagement programming, planning, and execution."* **Dougherty** recommended targeting *"feedback from a sample size of at least eight [BLV community members],"* and he advised on *"[conducting] the user sessions in-person, to build better connections with the BLV community, and to experience first-hand feedback and interactions with the prototype."* Thus, RAD was held primarily in person and eight participants were invited. The research team included real-life scenarios and activities during the program, as **Mouallem** recalled that *"LightHouse recommended activities related to real-life contexts"* to more effectively engage participants.

The RAD program provided participants with compensation for their time, additional compensation for transportation to and from campus for in-person programming, and meals, snacks, and drinks. **Dougherty** emphasized that programs similar to RAD must *"ensure that participant incentives are fair and aligned with the… rates for similar studies,"* and that *"the BLV community members… felt fairly compensated and were grateful for the experience to participate"* in RAD. Additionally, LightHouse received an honorarium for their support and engagement in the successful implementation of RAD. **Sheppard** thought of forms of *"remuneration and recognition"* beyond those we already adopted, by considering how *"the community partners [can] become co-participants, even in the writing of a proposal, and that could… in more ways, reflect the time and energy that they're putting into the project."*

In reflecting on the value of the community partnership to the nonprofit and the BLV community, **Dougherty** shared, *"This partnership and project allowed BLV participants to join the research, in the earliest stages, and provide their first-hand experiences with the prototype… along with sharing their real-life experiences [by] participating… as users with physical disabilities."* **Sheppard** also noted *"how complex this project really is"* and *"that all of these ideas take… time of individuals in that broader [BLV] community."*

7.5. Impressions and Takeaways About Co-Design

Participants and researchers alike reflected on new learnings and changing perspectives after the co-design process. First, the participants learned new design frameworks and skill sets that they saw themselves adapting in the future. **P3** saw themself *"[using] design thinking often"* after exposure to the design thinking framework via the co-design program. As for **P1**, they shared, *"I love co-designing and feel very humbled… to be invited to help unpack and offer feedback on a passion project that has undergone years of ideation and thoughtful application."* That being said, they saw themself adapting the process, *"[using] a sloppy iteration of this [co-design] process in [their] work as [they] learn from the community about what they want and need in order to plan… programs that will be affirming and engaging."* **P6** thought *"the process [was] very systematic, probably too systematic for projects at work or other projects, but [they] definitely appreciated the user-centric [empathy], definition, and ideation that [that] can incorporate at work and on projects."*

Participants used significantly positive terminology in describing their co-design experiences. **P1** shared that their experience *"[felt] super empowering"* and that they were *"grateful for the chance to revisit this process… and feel the power of being seen and heard."* **P6** felt invested, sharing that co-design *"increased [their] ownership and stake in the success of the tool."* Participants used terms such as *"affirming," "engaging",* and *"fun"* to describe their experiences with the tool and with the RAD content. They described how they *"[felt] confident," "gained confidence,"* were *"curious and [wanted] to experiment and learn [more],"* and *"felt pretty safe"* using the tools and completing activities. In setting up the RAD program, the research team emphasized the role of empathy in creating an inclusive, welcoming space for the participants during RAD. **Sheppard** added, *"[Participants] came to the table really wanting to talk about [their] world and have others understand it, just from human to human, but also, how can that understanding make the things that we design more effective and richer and really build more empathy towards one another?"*

Researchers reflected on the biases and false assumptions that they had prior to RAD. **Mendez Pons** shared that *"the co-design process highlighted assumptions she hadn't been fully aware of."* **Mouallem** elaborated, *"I made assumptions about BLV lived experiences being more uniform, and I ended up learning about the large breadth of prior experiences that participants had, be it with electronics, STEM education, or tool use."* She added, *"[I also made] assumptions about the time needed to complete an exercise in an accessible manner."* In fact, **Dougherty** emphasized the importance of *"[avoiding] going into the study with any biases or preconceived notions that you have the answers for the community that's the focus of the study."* By identifying their biases and assumptions via engaging with participants as fellow co-designers, the researchers were able to change their perspectives, and they also integrated changes into the program design accordingly, such as increasing the assigned activity time during RAD 2.0.

Co-designing an accessible engineering tool impacted participants' and researchers' perceptions of engineering education. Participants were interested to learn more, now that accessible media to do so existed. **P1** shared, *"I feel like I gained [enough] confidence to make me curious and want to experiment and learn from replicating or building bigger circuits."* **P6** said, *"[The tool] exercises my creative thoughts and [refreshes] my understanding of serial versus parallel circuits in a physical versus abstract format."* **Mouallem** shared that *"this project really clarified for [her] how engineering education is built upon so many pillars. If we want to improve its accessibility to learners with disabilities, it is not enough to strengthen one of the pillars."* She added that inclusive pedagogy and educator training would be necessary, in collaboration with other relevant entities. The researchers developed a keen eye for accessibility that would be of help in developing future educational content. **Rogando** was *"curious about the multiple avenues of potential design there,"* highlighting different features that could support accessibility, such as *"decreasing learning curves… or implementing multimodal feedback*" in conventional course offerings. **Mendez-Pons** reflected similarly, *"My understanding of accessibility in engineering education has been transformed, making me more aware of how to create learning tools that are both functional and meaningful for BLV learners."*

As for **Sheppard***,* she highlighted the complexity of co-designing for engineering education, in light of the dynamic and evolving roles of individuals involved. She commented, *"Because the community that you're wanting to engage are not experts [on engineering education], and even as they engage with you in that process, they do move from being novices, or they become less novice and more expert along the path, as they're giving you input, they're changing in terms of* *their status as learners… And that's what makes it a really hard design problem, because your partners are learners, and they're changing."*

To wrap up on the diverse and varied takeaways and impressions about co-design, **Dougherty** maintained, *"A big factor for the BLV community [to be involved] is the idea of "nothing about us without us"* [33]. Co-design brought together BLV participants and researchers, ensuring that an accessible engineering tool was designed through inclusive, collective efforts, centering the voices of the BLV community.

8. Discussion

The co-design process ***directly impacted participants and researchers, be it their perspectives, relationships, and experiences***. BLV participants discussed how co-design empowered them to make design decisions that were taken seriously and integrated into the improved tool design. Co-design centered their lived experiences and provided them with a sense of ownership over the designed tool. The process also increased their confidence in their abilities to contribute impactfully to improving the accessibility of engineering education. As for researchers, they pointed out that the co-design process unveiled biases and assumptions that they had about the experiences of the BLV community in engineering education. The process also brought to their attention multiple modalities that could support more intentional inclusion efforts in the field. Researchers reflected on the dynamic evolution of participants' and researchers' roles during the process, as everyone involved was learning and contributing diverse perspectives throughout. Co-design ensured equitable power allocation among the researchers and participants alike, as well as a trusting, supportive, and collaborative environment. The extensive, 2.5-year long process resulted not only in the design of the first BLV-inclusive simulator tool, but also in a collective, inclusive, and immersive design experience for everyone involved. Consequently, we argue that ***co-design can lead to creating more disability-inclusive engineering education resources*** when implemented thoughtfully, enriching the different design stages with diverse feedback based on co-designers' lived experiences.

8.1. Recommendations for Co-Designing Inclusive Engineering Education Resources

Below, we present several recommendations which can support the adoption and implementation of the co-design process with communities, in order to create disability-inclusive engineering education resources across engineering fields. These good practices and guidelines are categorized for different stages, in order to set up and integrate the co-design process with a successful community partnership. These recommendations are a synthesis of relevant recommendations put forth by prior literature and our findings, which interwove the experiences of participants and researchers with the co-design process.

Establishing the Community Partnership:

- Take time to build rapport and establish credibility with the community partner. This may take several months, and it is particularly important when you are working with minoritized communities that may have faced harm in prior exposure to research practices.
- Outline an agreement or understanding about the mission, goals, and expectations of the community partner and yours ahead of time, especially if you're planning a long-term partnership.
- Be open to modifying your plans. The community partner may bring up issues they consider more pressing to address, and you may be able to find middle grounds that answer your research questions and the community partner's prioritized needs.
- Offer fair compensation, which is of utmost importance. Ask the community partner about their expectations, and ask about the different forms of compensation that you can offer, such as transportation assistance.
- Carefully consider the different types of community partners that you can engage, as there could be advantages and disadvantages to each [48]. A referral by a trusted collaborator of the community partner, if possible, can establish credible grounds. Recruiting agencies may help address specific recruitment constraints and eligibility criteria, but they may recruit from a smaller sample of participants. Engaging with the community members themselves may be possible to recruit via word-of-mouth, but that may take more time.

Preparing for the Co-Design Process:

- As you create and plan materials, hold regular space for input from your community partner. You will likely receive diverse types of feedback, from the need for additional accessibility accommodations to recommendations on inclusive activities [49].
- Use accessibility checkers to review the accessibility of your digital documents for BLV participants. Consider extending the time allocated to activities to factor in screen-reader based navigation of multiple resources at a time.
- Consider designing activities that all participants can complete, even if they rely on different forms of assistive technology to do so. This also helps avoid prioritizing the needs of one participant over another's and invites all participants to be involved in all aspects of each activity [35].
- Conduct training sessions for researchers on interacting with and supporting participants when needed, and ask your community partner for input. For example, researchers may want to use degrees to describe walking orientations to BLV participants.
- Establish communication with staff in the finance department at your institution, and set up a suitable timeline for compensation disbursement and honorarium transfer to your community partner.
- As you are working with marginalized communities, prepare consent forms in advance and ensure that participants' identities are anonymized and protected.

- If you are interested in conducting research in relation to the planned co-design process, consider reflection-based scholarly frameworks, as the community members' reflections can provide important insight. For instance, the Research through Design (RtD) approach draws on reflective practices to generate new knowledge in the process of designing and critiquing artifacts [50], [51].

Implementing the Co-Design Process:

- To foster an inclusive environment for community members and researchers alike, create community guidelines collectively, and remind co-designers of them during the program. These guidelines can tackle topics such as collaboration during activities and navigating the physical space non-visually.
- If logistically feasible, plan the co-design process over multiple workshops or stages. This allows for gradually building rapport, trust, and comfort among participants from the community and researchers [49].
- Include activities that can benefit everyone involved. For example, plan a panel with BLV engineers and scientists to provide opportunities for networking and learning from real experiences in the field.
- Allocate sufficient time for exploration and tutorials prior to co-design activities, especially when using new, tactile resources or new software with digital screen readers.

Wrap-Up and Reflection:

- Dedicate time for individual and group reflection on the co-design experience. Be mindful of how co-design may surface diverse lived experiences, and encourage listening to others and learning from their experiences [52].
- Create pathways for optional further involvement. Some participants may be interested in co-authoring research, and researchers may be interested in volunteering for community events
- Check in with the finance department at your institution to ensure timely compensation of participants and the community partner.

8.2. Co-Design as a Pathway to Liberatory Design

It is worth noting that by co-designing with BLV community members at different stages of the process, we aligned our efforts with liberatory design, which meshes human-centered design thinking with deep equity practices [32], [53], [54], [55]. We met the different pillars of liberatory design as follows.

- Inequity has been designed into electronic simulators in the form of inaccessibility, excluding BLV learners. We worked to redesign such a system.
- Designing for equity requires the participation of those most impacted by marginalization and inequity. In this case, the BLV community was a serious partner in the design process.

- Power must be shifted between those who hold it, and those impacted by it. In our process, researchers did not hold any exclusive design power; rather, BLV participants held equally powerful roles in informing design changes and final decisions.

As a result, we believe that co-design can serve as a powerful tool to uphold the principles of liberatory design, enabling real equity in the outcomes of designing accessible educational technology tools.

8.3. Limitations and Opportunities for Future Work

Due to logistical, time, and resource constraints, eight participants joined RAD 1.0, and three returned for RAD 2.0. Additionally, while we worked to recruit participants with diverse lived experiences with blindness and low vision, we were unable to ensure full representation of BLV community experiences, such as deafblindness. We plan to work with a larger group in the future with a more diverse representation of lived experiences, to further enhance the inclusivity of our co-design process. Moreover, our study was conducted during RAD, a dedicated community engagement program. Future research can explore the feasibility and impact of integrating our proposed co-design framework into pedagogy for classrooms with disabled students. To support such efforts, we appended different resources and templates that we developed to ensure the successful implementation of RAD in Appendix B, and we invite the research community to adapt and improve our offerings in different contexts. Furthermore, while our research efforts focused on introductory engineering education, future research can explore the impact of exposure to accessible engineering tools on the long-term educational and career decisions of engineering students with disabilities.

9. Conclusion

This work explored the co-design of the first accessible electronics circuit simulator for blind and low-vision learners. Blind and low-vision community members and researchers collaborated over 2.5 years to co-design, prototype, evaluate, and improve the simulator tool. Qualitative data on participants' and researchers' experiences were collected via surveys and reflection entries and analyzed using the grounded theory approach. Based on our findings, we argued that co-design is an effective method for creating disability-inclusive engineering education resources, and we proposed several recommendations to support the adoption of co-design for disability inclusion via community partnerships. Co-design is a truly powerful method to center and amplify the voices of people with disabilities throughout the design process, in line with the slogan, "Nothing about us, without us."

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Appendix A: A Sample of Activities from the RAD Activity Workbook

Participants used the digital version of this workbook during the RAD program. They had the option to work on it directly on Google Drive or as a downloaded Word document using their digital screen readers. Researchers who facilitated these activities prepared additional resources to supplement what was provided in the workbook during the live sessions.

Apples Section (Part A): Simulator Activities

In this activity, you will go through the whole circuit design process. Feel free to ask the present researchers for any clarifications needed. Please think aloud during this activity!

Activity A.1: Calculating Current Values

1. You want to design a parallel circuit consisting of a current source connected across two resistors. The current source, the first resistor, and the second resistor are all connected in parallel. You are given the following values for the components:
   - R_1=300 Ohms
   - R_2=200 Ohms
   - I_{source}=5 Amperes

   Calculate the current across each resistor using the parallel resistance formulas that were shared in the primer. For reference, the formulas are as follows:

   If R_1 and R_2 are resistors in parallel, then:

   - $I_{R1} = [R_2 /(R_1+R_2)]*I_{source}$
   - $I_{R2} = [R_1 /(R_1 +R_2)]*I_{source}$

   We can further break down these formulas, so it is easier to calculate the needed values.

   Breaking down the formula $I_{R1} = [R_2 /(R_1+R_2)]*I_{source}$:
   Let $A = R_1+R_2$.
   Let $B = R_2/A$
   Then $I_{R1} = B*I_{source}$.

   Similarly, breaking down the formula $I_{R2} = [R_1 /(R_1+R_2)]*I_{source}$:
   Let $C = R_1+R_2$.
   Let $D = R_1/C$
   Then $I_{R2} = D*I_{source}$.

   I_{R1} = *[Provide answer here]*

   I_{R2} = *[Provide answer here]*

2. Set up the proposed circuit design using the available tool. Go through the physical then digital design processes. Do not forget to place a ground component.
3. Use the digital simulator to calculate the current values across each resistor. Use the DC operating point as your simulation type. You can leave any optional fields empty.

   Simulator I_{R1} = *[Provide answer here]*

   Simulator I_{R2} = *[Provide answer here]*

4. Do your calculated current values match the simulator values? Do not worry about small decimal differences due to rounding.

   [Provide Yes/No answer here]

Activity A.2: Predicting the Change in Current Values

Clear your circuit design, and start a new one for this part. **Continue to think aloud.**

1. Set up a simple circuit with a voltage source in series with one resistor. Don't forget the ground component. Use the values V_{source}=10 V and R=50 Ohms. Go through the physical then digital design process.
2. Use the simulator to find the current across the resistor, still using the values V_{source}=10 V and R=50 Ohms. Record this current as I_{50}. You can set your simulation type to DC Operating Point, and leave any optional fields empty. *Tip: If you get a negative current value, flip the orientation of your voltage source (i.e., if the orientation was Bottom, it becomes Top. If it was Right, change it to Left, and so on).*

   I_{50}= *[Provide answer here]*

3. Find the current if we increase R to become R=100 Ohms. Record this current as I_{100}.

   I_{100}= *[Provide answer here]*

4. Find the current if we further increase R to R=200 Ohms. Record this current as I_{200}.

   I_{200}= *[Provide answer here]*

5. Fill the following table with your obtained values in the previous parts.

Current	*Value*
I_{50} for R=50 Ohms	*[Provide answer here]*
I_{100} for R=100 Ohms	*[Provide answer here]*
I_{200} for R=200 Ohms	*[Provide answer here]*

6. Do you notice a trend in the current values based on the change in resistance values? Explain.

    [Provide answer here]

7. Do you expect the current to increase or decrease if we change R to R=500 Ohms? You don't need to calculate the numerical answer, we just want you to state the expected trend in the change (increase/decrease).

    [Provide answer here]

8. Do the simulation results agree with Ohm's law? Please explain. For reference, Ohm's law states that Voltage = Resistance * Current.

    [Provide answer here]

Bananas Section (Part B): Collaborative Activity

In this activity, you will work with an assigned peer. Please continue to think aloud together!

Activity B.1: Reviewing Our Collective Recommendations

As a group, we will all review the collectively generated recommendations for collaboration.

Activity B.2: It's Almost Autumn!

1. The autumn season is right around the corner. The weather is getting colder. You just took your sturdy, old, reliable heater from storage. However, it won't turn on, and something seems broken. As an engineer, you decide to take matters into your own hands and fix the heater.
    - You remove the heater's electronic circuit board and scan it.
    - Your scan generates the file BrokenHeaterCircuit.json [link here]. This file format is compatible with our simulator tool!
2. To start, import the file BrokenHeaterCircuit.json into your digital simulator. You will need to find the problem with this circuit. Here are some steps to help:
    a. Navigating the circuit digitally may be overwhelming. You can replicate it on your physical board for hands-on spatial navigation.
    b. Your circuit contains many resistors. The resistor with the largest value is the component that dissipates electricity in the form of heat, thus generating warmth from the heater. Other, much smaller resistors may be there to regulate other circuit aspects. What is the current flowing through your main heating resistor in the circuit? *[Provide answer here]*
    c. Explore your physical replica of the circuit and think of the current value you found in part B. Once you find the problem, describe it briefly below. Frequent use of wires may cause them to melt or break. Is this possibly related to the problem in your

circuit? At this stage, feel free to discuss your hypothesis with a present researcher if needed!
[Insert answer here]

3. Now that you've detected the problem, the engineer in you wants to fix it. In other words, you need to debug your circuit. Try adding a simple component to fix the circuit, and simulate for the current value flowing through the heating resistor. Record the current value across the heating resistor below. You can use the DC Operating Point simulation type.
   I = *[Insert answer here]*.
4. After fixing the circuit, you decide to tinker a bit further to improve your circuit design, by reducing how much current your heater consumes. Your local hardware store sells three heating resistors that you can substitute into your circuit: 11,000 Ohms, 900 Ohms, and 50 Ohms. Using the simulator, choose the right resistance value that will help you reduce the current. *Hint: You found the current value flowing through the heating resistor in the previous part. Now, you're aiming for a smaller current value than that!*
   New resistance value R = *[Insert answer here]*.

Congratulations, you just fixed and improved your heater! Way to go, engineer!

Coconut Section (Part C): Co-Design:

This section involves a set of in-person activities that will be facilitated by the researchers.

<u>Activity C.1: Reviewing Design Thinking and Co-Design</u>

First, we will begin with a refresher on the design thinking process and its five stages: empathize, define, ideate, prototype, and test.

<u>Activity C.2: Warmup</u>

We'll play the New Choice! game, which is pretty popular at the Stanford d.school.

<u>Activity C.3: Think, Pair, Share</u>

Prompts:

- What went well with the exercise we just did? What was rewarding?
- What didn't go well? What was challenging?
- What were your impressions about using the import/export function for debugging?
- What was your experience working with someone versus working individually?
- Impressions about the collectively generated recommendations for collab work

We will also play the Wheel of Questions.

Activity C.4: Dive into the Past

Prompts:

- What was noticeable to you in comparing the old tool?
- Were there any changes that you felt strongly about?

Activity C.5: Individual Activity

We'll create a Word Cloud. You can find its link here. You can also journal in this space!

Dragon Fruit Section (Part D): Final Survey:

Please fill the final survey at this link by [*date*]. The survey will take around 20 minutes to complete.

Appendix B: Researchers' In-Person Guide

Participant Information

Name	**Visual Ability**	**Email**	**Phone Number**	**Participant's Workbook Link**	**Food Allergies**	**Assigned Wifi Username**

Schedule

Time	**Activity**	**Location**	**Participants & Researchers Present**	**Any Notes**
9:00 am - 9:20 am	Arrival + hand out materials (board + reference guide + tile boxes)	Main Space	Everyone	Researchers arrive starting at 8:45 am if possible.

9:20 am - 9:25 am	Orientation around the space and available resources (snacks, drinks)	Main Space	Everyone	R1 welcomes everyone. R2 leads the announcements.
9:25 am - 9:35 am	Introductions. Proceed to the assigned activity rooms.	Main Space	Everyone	R2 leads the introductions and asks for a fun fact.
9:35 am - 10:50 am	Participants complete the multi-part simulation activity individually using the simulator tool.	Main Space	P1, R3	
		Design Studio	P3, R4	
		Office	P2, R2	
10:50 am - 11:00 am	Break time	Main Space	Everyone	
11:00 am - 11:50 am	Participants complete a collaborative activity with a peer using our improved electronics simulator tool.	Main Space	R2 leads	R1 to receive lunch meanwhile.
		Design Studio	R3 and R4 lead	
11:50 am - 12:00 pm	Break time and distribute lunches.	Main Space	Everyone	Food allergies listed in the Participants Information section.

12:00 pm - 12:50 pm	Participants complete a co-design reflection activity with peers and researchers, individually, in pairs, and collectively.	Main Space	Everyone	Everyone can eat during this hour. R3 leads. R2 co-leads when needed. R4 and R1 go around during breakouts.
12:50 pm - 1:00 pm	End of program announcements and departure.	Main Space	Everyone	R2 leads the announcements (the survey – what content to expect)

Advice for Interaction with Participants

Whether this is your first experience working with the blind and low-vision community or just another regular collaboration, the following can help ensure a healthy, positive experience for all.

- Always ask before offering help.
- Always introduce yourself (*first time:* name + affiliation, *second time onwards*: name).
- Do not move participants' belongings before/without asking permission, notifying them, or asking them to do so (and offering to help if needed).
- If you're running a session, it's helpful to describe out loud the setting of the room to the participant (e.g. here's the chair facing a desk. There is a physical grid board set up in front of you, blocks you will need to your right, etc.).
- If you are walking participants somewhere, you can describe the space out loud (e.g., we will take a 90 degree turn to the right, now, to arrive in the main meeting space).
- When time runs out for your session, if participants are not done with the activity, gently let them know that time is out, and remind them that we're not quizzing them on their speed or correct answers, but we want to learn about their experiences with the tools.

Helpful Documents to Keep on Hand

- Researchers' Activity Workbook Answer Key
- Collective Collaboration Plan (generated by the participants)
- Quick, uncontracted Braille translator: [Braille Translator by Two Blind Brothers]
- If you're leading a session involving the use of VoiceOver, familiarize yourself with the software (or refresh your memory). Go to *Apple → System Settings → Accessibility → VoiceOver*, and complete the tutorial (~ 20 mins).