Community-based participatory research to inform the design of electronic problem-solving training for individuals with traumatic brain injury

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Table of Contents

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Abstract

Background: Traditional rehabilitation research often excludes the voices of individuals with lived experience of traumatic brain injury (TBI), resulting in interventions that lack relevance, accessibility, and effectiveness. Community-Based Participatory Research (CBPR) offers an alternative framework that emphasizes collaboration, power-sharing, and sustained engagement with patients, caregivers, and clinicians.

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Methods: A multi-step, mixed-methods design case methodology was adopted, guided by CBPR principles and Learning Experience Design (LXD). Participatory mechanisms included a 33-member Community Advisory Board (CAB) and 10 Community Engagement Studios (CES), which engaged TBI survivors, caregivers, clinicians, and researchers throughout the Discover, Define, Develop, and Deliver phases of the Double Diamond model. Iterative activities included empathy interviews (n=14), persona development (n=10), rapid prototyping, and usability testing with five TBI participants using think-aloud protocols and the Comprehensive Assessment of Usability for Learning Technologies (CAUSLT).

Results: Usability evaluation demonstrated high user satisfaction with CAUSLT scores averaging 87.3 out of 100 and 80% accuracy on knowledge assessments. The participatory process yielded three key findings: (1) iterative community feedback directly enhanced technical usability through specific design modifications including microlearning modules (5-12 minutes), badge system refinements, and voiceover tone adjustments; (2) multi-stakeholder representation systematically identified design considerations that single-stakeholder approaches overlook, with caregivers contributing family involvement features, clinicians providing evidence-based validation, and individuals with lived experience prioritizing autonomy elements; and (3) TBI-specific design requirements emerged, including the need for linear content progression over branching navigation, higher technical performance standards, and explicit content signaling with clarity prioritized over novel interface design. Think-aloud protocols revealed that participants struggled with mobile navigation and branching structures but excelled with sequential content progression. This study provides evidence that systematic CBPR implementation produces measurable improvements in rehabilitation technology usability while contributing methodological insights for participatory design in cognitive rehabilitation.

Conclusions: This study provides evidence that systematic CBPR implementation produces measurable improvements in rehabilitation technology usability while contributing methodological insights for participatory design in cognitive rehabilitation. Findings demonstrate that sustained community engagement (spanning entire development cycles) creates superior technical outcomes compared to traditional consultation approaches, establishing CBPR as both an ethical imperative and practical methodology for developing effective, accessible rehabilitation interventions.

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Keywords: Traumatic Brain Injury; Community-Based Participatory Research; User-Centered Design; Usability; mHealth; Rehabilitation; Problem-Solving Training

Introduction

Traditional rehabilitation research often fails to include the voices of people with lived experience of disability.[1,2] This is particularly evident in the case of traumatic brain injury (TBI), in which interventions are largely based on expertise-driven and institution-centered models and in which participants' voices and needs tend to be underrepresented.[3,4] TBI is an acute but also chronic health condition with a high risk of neurological disorders caused by a range of external forces, such as motor collisions, accidents, sports, and work-related injuries.[5,6] TBI survivors often suffer from persistent cognitive and physical challenges, including limited attention, social functioning, information processing, and self-awareness;[7] emotional irregularities, including executive deficits, emotional lability, and irritability;[8] as well as impulsivity[9] and social dysfunction.[10] These post-TBI challenges can place individuals at a disadvantage in social and learning contexts[11] and may hinder their access to rehabilitation services.[12] When designers fail to account for affected individuals' needs and life challenges, the resulting solutions may be misaligned with clinical realities and patient contexts, leading to interventions that lack relevance, diminish user engagement, and fall short of meeting the complex needs of those who have sustained a TBI.[13]

While the challenges experienced by individuals with TBI are increasingly acknowledged, rehabilitation research has not consistently translated this awareness into robust community member engagement or integration of practitioner perspectives.[14,15] Provider-centered and institution-focused models risk deepening inequity in TBI rehabilitation research and sustaining power imbalances between professionals and the individuals they aim to serve.[16] Insufficient collaboration across researchers, clinicians, and patients can impede the development of effective rehabilitation interventions, often manifesting as passive, provider-dominated clinician-client relationships.[17] When research processes are shaped by unequal influences and limited collaboration, interventions risk being less responsive to the needs of individuals with TBI.[18] This can lead to diminished user satisfaction and overall intervention effectiveness.[19,20] Singular models or prescriptive frameworks are unlikely to be able to resolve these issues.[21,22] Instead, there is a need for those who typically lead intervention design (i.e., researchers, clinicians, designers, etc.) to critically examine and experiment with more collaborative approaches that seek to support more symmetrical and responsive rehabilitation efforts.[23] The present work offers a case example of how such approaches can be enacted in practice.

We argue that power-sharing and collaborative decision-making are critical to developing interventions that are both effective and contextually responsive.[24,25] Rehabilitation itself is inherently multifaceted, requiring real-world interaction, collaboration, and adaptability to individual needs.[26] Participatory approaches offer one path forward by shifting decision-making influence from researchers and providers toward the community and individual community members.[27] This shift has been shown to generate meaningful change in health-related research contexts.[28] Ethnographic research by Manhas and colleagues[29] demonstrates how shared decision-making in rehabilitation research can enhance patient satisfaction, understanding, goal attainment, and self-reported outcomes. Findings highlight important contrasts between traditional provider-driven approaches and community-based methods. While the former often limits patient involvement and flexibility in care planning, the latter emphasizes collaboration and empowerment, thus supporting individuals in addressing rehabilitation challenges and creating space for sharing personal experiences.

Challenges such as limited community member engagement, asymmetrical decision-making, and provider-centered research models have the potential to compromise the relevance and impact of TBI rehabilitation efforts[16–18,30]. Such challenges suggest a need to explore more inclusive approaches that emphasize more symmetrical decision-making and meaningful collaboration with the TBI community[31]. To explore what a more inclusive and collaborative approach to TBI rehabilitation research might look like in practice, this study presents a case example of the formative design and evaluation of *Electronic Problem-solving Training* (ePST). ePST is a metacognitive, evidence-based mobile health (mHealth) problem-solving intervention.

ePST is based on problem-solving training (PST), a cognitive-behavioral approach with proven efficacy for neurodevelopmental and psychological conditions that is grounded in some of the strongest evidence in cognitive rehabilitation. [32,33] PST is widely used in psychology to improve problem-solving skills and mindset[34,35] and has shown promise in preventing and treating cognitive deficits[36] through numerous clinical trials.[37] Research suggests PST can be especially beneficial for long-term or multifaceted health issues, such as TBI.[38,39] A robust body of evidence shows that such problem-solving approaches lead to meaningful reductions in symptoms, strengthen individuals' confidence in managing their health, and enhance adherence to prescribed regimens.[40–42]

ePST was created through the lens of Learning Experience Design (LXD[43] and grounded in a Community-Based Participatory Research (CBPR[44] framework to support more symmetrical influence in design, accessibility, and community member-driven decision-making. To address these challenges, the current study presents the formative design and evaluation of ePST, a metacognitive mHealth intervention for individuals with TBI. We applied a community-based participatory research (CBPR) framework and Learning Experience Design (LXD) principles to ensure meaningful, ongoing collaboration with individuals with TBI, care partners, clinicians, and researchers.

Background and Rationale

Rehabilitation research has traditionally been guided by clinician and designer perspectives over patient input, raising concerns about the relevance, effectiveness, and adaptability of interventions for individuals with TB.[45,46] This is problematic in that, as Correa et al[47] suggest, interventions designed without patient involvement can fail to reflect how patients perceive risks, benefits, and treatment goals. This can ultimately affect participant recruitment and randomization. Sawidan et al[48] highlight the wide variation in treatment outcomes for individuals with TBI and suggest that this heterogeneity is partly due to insufficient attention to individual factors such as injury severity, therapy duration, and personal recovery needs. Challenges such as these, stemming from limited patient involvement in rehabilitation research, suggest a need for more adaptive, user- and patient-informed approaches that can enhance the relevance, responsiveness, and overall quality of interventions. CBPR offers one such framework for supporting more inclusive, context-sensitive, and ethically grounded approaches, particularly in the context of TBI.

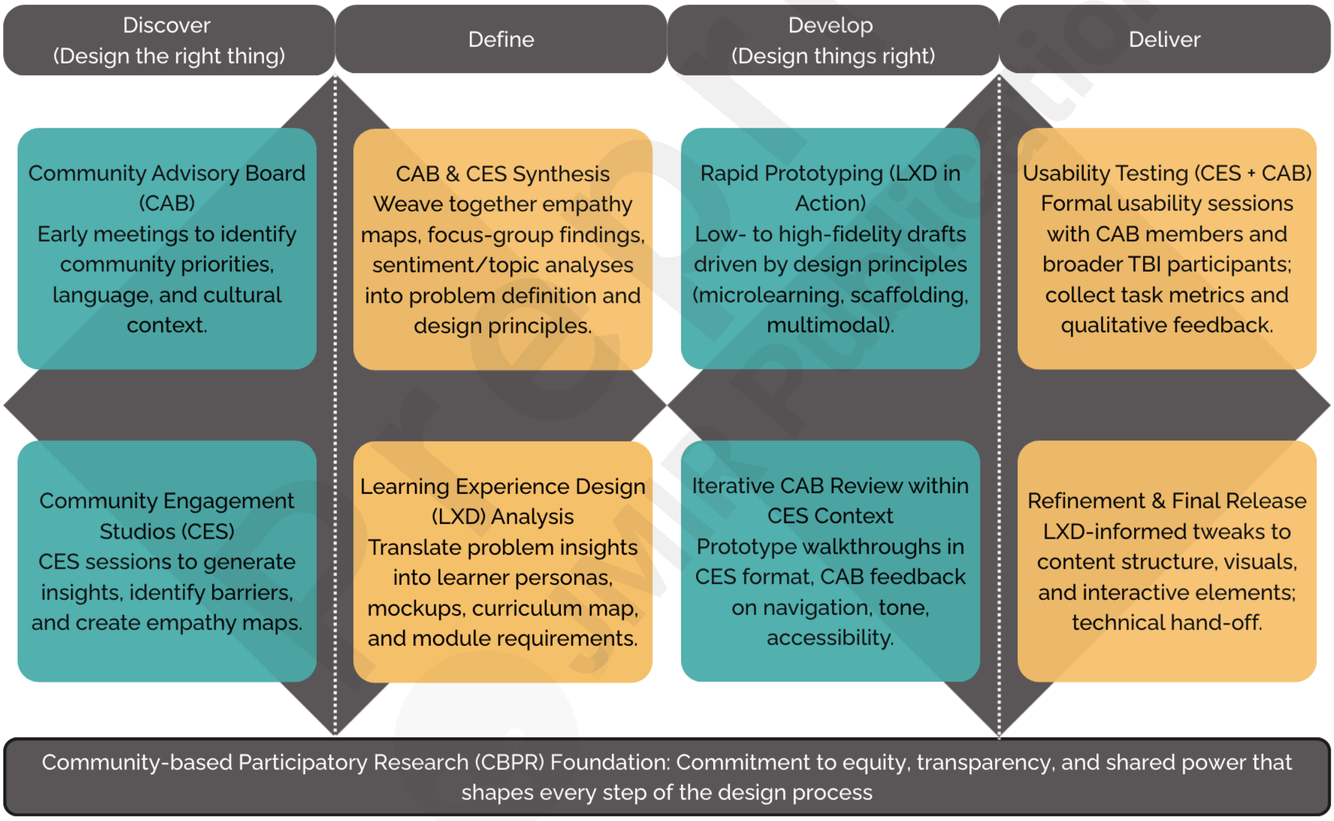
In the context of TBI rehabilitation, CBPR enables researchers to better understand the nuanced lived experiences of individuals with TBI and their caregivers, supporting the co-creation of interventions that are more relevant, acceptable, and effective. As an example, Quilico et al[24] partnered with individuals with TBI and their caretakers to adapt a physical activity program, resulting in modifications that enhanced program relevance, improved health outcomes, and increased participant engagement. Similarly, Groussard and colleagues[49] involved users with lived TBI experience and their caregivers in the development and evaluation of a cognitive impairment support system, which led to improved user satisfaction and greater autonomy in technology use. Examples such as these underscore the promise of CBPR in promoting relevance, acceptability, and effectiveness. However, participation alone is insufficient in CBPR; what is needed in addition are reciprocal relationships among the target community, academic collaborators, and practice partners that draw on the strengths, expertise, and diverse experience of each group.[50] To this end, understanding how CBPR is structured can clarify how it promotes sustained, power-sharing relationships among all partners. Springer and Skolaru[51] offer one such framing, defining CBPR by distinguishing between its two core components: *"community-based,"* which refers to groups connected by shared identity, such as race, gender, beliefs, or a collective commitment to a specific cause, often through a community-based organization, and *"participatory,"* which emphasizes the collaborative partnership between researchers and community members throughout the research process.

Conceptual Framework

Designing rehabilitation interventions for individuals with TBI presents complex challenges, as traditional approaches often fail to tailor to their needs and lived experience. [52,53] While participatory and user-centered approaches are increasingly used in health-related research, few frameworks integrate health equity, community engagement, and learning design in a cohesive, systematic way.[54] To address this lack of integration across domains, we devised a conceptual framework that positions CBPR as the methodological foundation, incorporates participatory methods such as the CAB and CES, and applies the LXD framework to translate input into concrete design. We then mapped these three strands onto the Double-Diamon[43,442] model (Figure 1), a framework that has been applied previously with success in digital health interventions. CBPR underpins the entire cycle, ensuring equity and shared power from start to finish; the CAB and CES drive the Discover and Define phases by identifying and synthesizing community insights into clear problem statements and design principle;[57,58] and LXD guides the Develop and Deliver phases by converting those principles into iteratively refined prototypes, structured CAB/CES feedback sessions, and final usability testing that yield concrete, user-centered intervention features.

Figure 1

CBPR, CAB/CES, and LXD framework mapped across the Double-Diamond design cycle.



CBPR as Foundational Ethos

We adopted CBPR as a foundational ethos in our design, which is increasingly recognized as a promising approach for developing more inclusive, user- and patient-centered rehabilitation intervention.[59,60] Rather than treating patients as passive recipients of care, CBPR emphasizes collaboration throughout the research process, which can support more authentic translation of community priorities into clinical practice.[61,62]

Key Principles of CBPR. Community-based participatory research shifts emphasis from researcher-driven agendas to the lived experiences of target communities, which can result in outcomes that are not only more relevant and acceptable but also more effective.[63] Central to CBPR is a commitment to collaboration and balanced partnerships that support shared responsibility in decision-making.[64] In contrast with short-term, investigator-led studies that may lack sustained engagement, CBPR emphasizes long-term, reciprocal relationships that promote ethical research practices and contribute to improved outcome[65]. Studies characterized by limited duration and top-down research priorities have been critiqued for overlooking local needs, which can lead to perceptions of exclusion and a lack of trust in the research process. [66,67] These concerns have persisted across health research broadly, often limiting the extent to which community members can influence study design and implementation. Standardized research practices that do not readily accommodate community input can further perpetuate these issue[67].

Role of CBPR. CBPR's emphasis on shared decision-making across all phases of the research process provides one avenue to address these problem.[68] Collaboration through structured partnerships allows community members to inform priorities, participate in knowledge creation, and strengthen the real-world applicability of interventions.[27] These approaches move research beyond expert-driven agendas by integrating the lived experiences, priorities, and contextual knowledge of community members into the design and implementation proces.[69]

Participatory Mechanisms

Community Advisory Board. Community Advisory Boards (CABs) are structured, ongoing partnerships that support CBPR by integrating the voices of individuals with lived experience directly into the research proces.[70] Community Advisory Boards typically consist of stakeholders who share common identities, interests, or health experiences, allowing for authentic representation and culturally grounded input throughout the project lifecycl.[71–73] More recently, CABs have been applied in rehabilitation to deepen understanding of community need[74], health priorities, and cultural relevanc.[75] Unlike short-term focus groups, CABs are distinguished by sustained meeting routines for stakeholders to co-develop research strategies, advise on ethical and contextual issues, and guide intervention refinemen.[76] The role of community members helps foster shared leadership, trust-building, and power-sharing between them and researchers.[77] In the current study, our CAB included TBI community members, researchers, and clinicians working together to shape content and ensure that the ePST intervention remained aligned with the needs and priorities of the TBI communit.[78,79]

Community Engagement Studios. Community Engagement Studios are structured and facilitated consultation sessions in which researchers meet with panels of community experts, caregivers, and clinicians to provide targeted feedback on study design, intervention strategies, and implementation. Unlike traditional advisory boards or focus groups, which often provide limited or unsustainable feedback, CES emphasizes focused, iterative sessions that foster open dialogue, reciprocal learning, and sustained community involvement across the research lifecycl.[58,80] Developed by the Meharry-Vanderbilt Community-Engaged Research Core in 200[57], the CES methodology was created to address longstanding barriers to participation in clinical and rehabilitation research, including mistrust rooted in historical unethical practices and social inequitie.[81] By positioning community members as consultants and experts rather than passive participants, CES helps researchers identify barriers, adapt interventions to community needs, and build trust with underrepresented group.[82,83]

CES can enhance cultural adaptatio[84], increase minority participatio[82,83], and reduce power imbalances between researchers and community member.[85,86] In this study, CES were used as a participatory mechanism to improve the relevance, accessibility, and cultural fit of ePST for individuals with TBI. Specifically, CES supported the CBPR framework by ensuring that feedback from individuals with lived experience directly informed the design, refinement, and implementation of ePS.[57,79] This participatory process helped tailor the intervention to the cognitive, emotional, and social needs of the TBI populatio.[59]

Operationalization via Learning Experience Design

The development of ePST was guided by LXD, a learner-centered, theoretically grounded framework that integrates instructional design, cognitive science, user experience (UX), and participatory approaches. [87,88] LXD emphasizes designing engaging and inclusive learning environments that respond to learners' real-world needs and experience. [89,90] LXD focuses on the cognitive, emotional, and perceptual influences of learner interactions with content, tools, and people across the learning process. [91–93]

In ePST, LXD principles were applied through a learner-centered design process aligned to the Double-Diamond model. In the Discover phase, empathy interviews revealed key needs and challenges. During the Define phase, those insights (together with CAB feedback) shaped persona development, module structure, and mockup content design. [94,95] To address common TBI cognitive challenges, such as memory impairments and fatigue, the Develop phase structured ePST around microlearning principles, using short, digestible lessons to reduce cognitive load and support retention. [83–86] Finally, in the Deliver phase, usability testing validated these designs and informed final refinements.

Multimodal learning strategies, including text, visuals, voiceovers, and interactive elements, were incorporated in the Develop phase to accommodate diverse preferences and reinforce learner understanding.[100] Gamification features such as badges, progress indicators, and interactive tasks were added to boost motivation and engagement.[101] Accessibility-first and adaptive design strategies were adopted to enable users to navigate content at their own pace with reduced cognitive demands.[102] Emotional and behavioral design elements, including storytelling and incorporation of real-life scenarios, fostered empathy and user connection, consistent with TBI rehabilitation best practice. [103] These features were evaluated and optimized through usability testing in the Deliver phase.

Sociotechnical-pedagogical Framework. The Sociotechnical-pedagogical framework (STP) conceptualizes learner experience as the product of alignment among three interdependent domains: technological, pedagogical, and sociocultural.[104,105] The technological domain encompasses reliability, accessibility, device compatibility, navigability, and error tolerance. The pedagogical domain addresses coherence among objectives, materials, activities, and assessment, along with clarity of explanations and scaffolding, cognitive load management, and feedback quality. The sociocultural domain covers presence and identity, communication and collaboration, cultural responsiveness, and the degree to which scenarios feel authentic and respectful. STP has been formalized as both a design and evaluation lens in learning experience research, accompanied by dimension-specific heuristics that make the construct actionable for reviewers and designers. Empirically, these heuristics have been derived from literature and validated through analysis of real course evaluations, yielding a concise set that uncovered 195 distinct problems and consolidated them into 14 nonoverlapping heuristics spanning the three domains.[104]

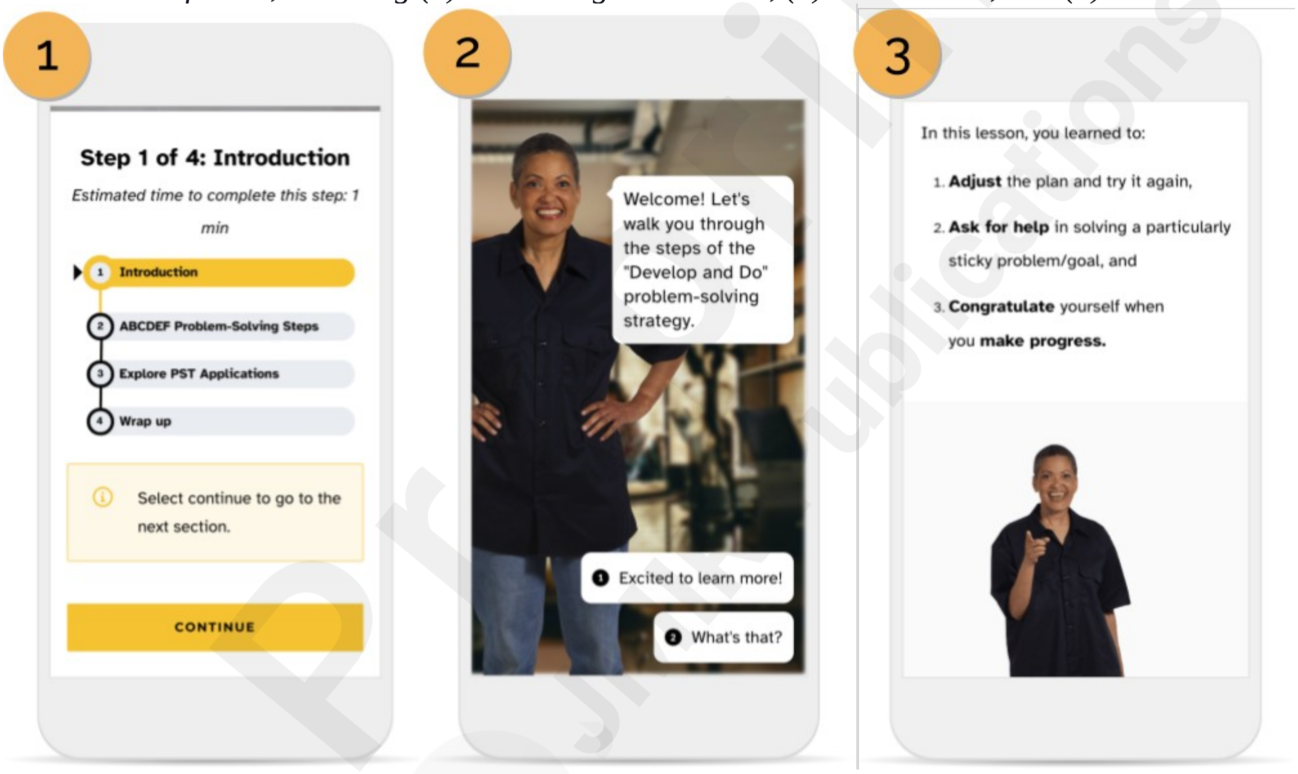
This multi-dimensional approach proves especially critical in neurorehabilitation contexts, where traditional usability frameworks often miss the complex interplay between cognitive, social, and technological factors.[88] For individuals with TBI, technological considerations extend beyond standard accessibility to include cognitive load reduction through simplified interfaces, memory support features, fatigue accommodation, and compatibility with assistive technologies. Pedagogical factors must address executive function challenges through enhanced structure and predictability, compensatory strategy instruction, repetition mechanisms, and metacognitive skill development that supports self-awareness and learning transfer. Sociocultural considerations encompass stigma reduction, identity reconstruction following brain injury, peer support integration, family involvement, and the unique social challenges accompanying cognitive rehabilitation.

STP systematically identifies issues that purely technical reviews miss such as low social presence despite acceptable interface metrics, or misalignment between instructional sequence and culturally responsive content, making it ideally suited for complex rehabilitation interventions. In our study, STP served as a critical design lens for triangulating evidence across think-aloud observations, CAB feedback, quantitative survey data, etc. Items from the Comprehensive Assessment of Usability for Learning Technologies (CAUSLT) instrument[106] were mapped to the three STP domains, enabling integrated interpretation of findings and prioritized remediation that improved fit across technological, pedagogical, and sociocultural domains.

Intervention Description. ePST is a cross-platform, community-informed intervention designed to meet the cognitive and emotional needs of individuals with TBI. Based on microlearning principles, the course features short, digestible lessons (5–12 minutes) with chunked content and built-in progress tracking to reduce cognitive load. To enhance engagement, ePST incorporates motivational messaging drawn from empathy interviews, a virtual coach named Ruth, and personalized learning experiences. Additional features such as reminders embedded throughout the learning sequence and gamified elements like badges and certificates were developed to support memory, reinforce learning, and maintain user motivation (Figure 2).

Figure 2

Screenshots of ePST, including (1) ePST Progress Tracker, (2) Coach Ruth, and (3) Reminders.



ePST was created based on PST principles, specifically a step-by-step strategy involving a six-step process embodied in the mnemonic of “A-B-C-D-E-F:” (A) Assess the Problem: identify the specific challenge; (B) Brainstorm Solutions: generate potential solutions to address the problem; (C) Consider and Choose: weigh options and select the best solution; (D) Develop and Do: implement the chosen plan; (E) Evaluate: evaluate the effectiveness of the plan; and (F) Flex and Adapt: revise and improve the plan if necessary. This process is illustrated in Figure 3. ePST applies this framework to equip individuals with TBI with structured strategies to improve decision-making and problem-solving.

Figure 3

Problem-solving training strategy

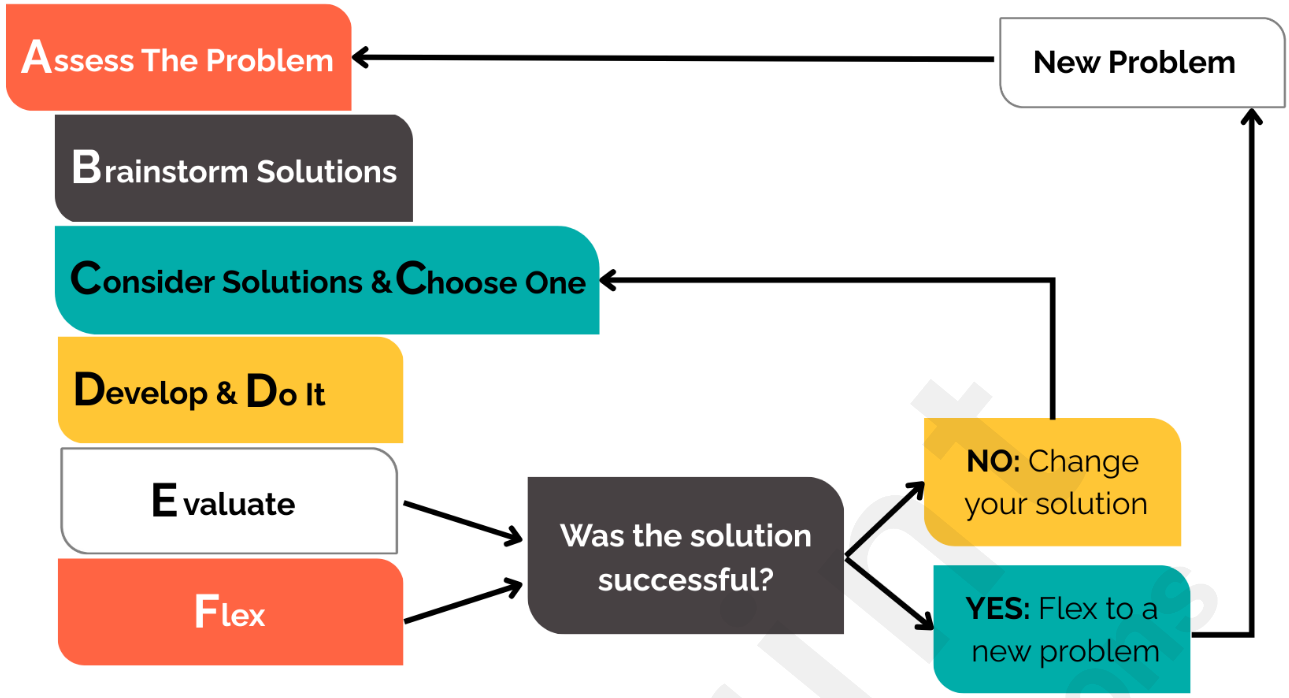


Table 1 below presents an overview of the five core modules that comprise the ePST intervention. Each module was designed according to user-informed design principles discussed later in this paper. Initial development efforts prioritized Modules 2 ("The ABCDEF Steps to Problem-Solving") and 4 ("Deep Dive into PST Steps"), as these form the conceptual foundation of the PST strategy at the heart of ePST. Early prototypes of these modules were developed using storyboards and underwent internal design critique within the development team. A second draft was then implemented as a high-fidelity prototype using Articulate Rise and reviewed by subject-matter experts (SMEs) for content validation and refinement. The third version was shared with CAB members for additional critique, usability testing, content revision, and quality assurance. Figure 4 illustrates sample improvements to one design element based on this iterative feedback process. Once finalized, Modules 2 and 4 served as templates for the development of the remaining modules, ensuring consistency in structure and instructional approach across the course.

Table 1

Overview of ePST modules

Module Number	Module Name	Module Description
Module 1	Introduction to Problem-Solving Training	An introductory module that sets the stage for understanding the importance and methodology of PST
Module 2	The ABCDEF Steps to Problem-Solving	A foundational module that introduces the six-step ABCDEF approach to problem-solving
Module 3	Stress Identification and Management	A module focused on recognizing and managing stressors that can impact problem-solving capabilities.
Module 4	Deep Dive into PST Steps	An in-depth exploration of the PST steps, providing a more comprehensive understanding

		of each phase
Module 5	Real-life Application, Resources, and Support	A module that provides additional tools, resources, and contact information to support learners in their PST journey

Figure 4

Example improvements to the badging component of modules

Methods

The purpose of this iterative, formative design and evaluation case study was to use a CBPR approach to guide front-end design activities (i.e., empathy interviews, empathy mapping, and persona development) and to evaluate the sociotechnical-pedagogical usability of the ePST intervention with TBI community members (i.e., CAB members, families, providers, and individuals with lived TBI experience) at a large public university and a large medical center in the Southern United States. The questions that guided this research included:

RQ1. What themes related to learning needs, barriers, and preferences emerge from front-end design activities (empathy interviews, empathy mapping, and persona development) with TBI community members?

RQ2. How did individuals with TBI perceive the sociocultural, technological, and pedagogical usability aspects of their experience with ePST during testing?

RQ3. How were identified sociotechnical-pedagogical usability issues addressed through design refinements?

Research Design

The formative design and evaluation of ePST followed the Double-Diamond design approach, applying its four iterative phases to structure discovery, problem definition, development, and formative evaluation. In the Discover phase, we established the CAB, drafted design principles, and held CES empathy interviews with individuals with TBI. In the Define phase, we developed learner personas, drafted a curriculum map, and engaged in ongoing cycles of CES sessions and CAB reviews. In the Develop phase we engaged in design, planning, and prototyping to create a design proof that comprised a complete draft of all content, which was reviewed by the CAB. Finally, in the Deliver phase, we engaged in usability evaluation with individuals with lived TBI experience, with refinements and optimizations made after each round.

Procedures

ePST was created using the Double-Diamond framework to structure our formative design and evaluation. Given the highly iterative nature of this approach, data analysis was multimodal and occurred across all phases of the design cycle. Data analysis fell into three broad categories: (1) qualitative, (2) quantitative, and (3) computational. We describe the phase-wise procedures and associated data analytic approaches in the below sections..

Discover Phase Procedures

In the Discover phase, we established a CAB, used computational analysis of relevant documents to surface preliminary design principles, and conducted empathy interviews.

Establishment of the Community Advisory Board. We established a CAB to facilitate sustained collaboration and ensure transparency and mutual respect in the design process. CAB members were recruited using purposive sampling from academia, industry, and medical-related institutes. CAB members were recruited using purposive sampling[107] from the community, academia, industry, and medical-related institutes based on four criteria: (1) professional expertise in TBI rehabilitation, assistive technology, and digital health; (2) lived experience with TBI (individuals and family members/caregivers); (3) demographic diversity across age, gender, socioeconomic status, and geography; and (4) community member representation including those with lived experience, clinicians, researchers, technology developers, and advocacy organizations. Quarterly CAB meetings were held across Phases 1-3 (total n = 16). CAB members were compensated $25 for each CAB meeting.

Establishment of Preliminary Design Principles. We drew on findings from a prior study, *Caregivers in Dementia PST/DSJ* (CaDeS), which employed a similar problem-solving training model.[108] Participant survey responses from CaDeS were analyzed using machine learning techniques, including sentiment analysis and Latent Dirichlet Allocation (LDA), to generate an initial set of seven design principles for ePST. These draft principles were subsequently reviewed and refined in a structured CES session with the CAB.

Empathy Interviews. Empathy interviews were conducted with three groups of participants. Groups 1 and 2 consisted of TBI survivors (n = 6 and n = 3, respectively). Group 3 consisted of care partners and providers (n = 5). Interviews were guided by Kouprie & Visser's[109] four-phase empathy framework. All interviews were conducted online using Zoom web conferencing software. Participants were recruited from a large medical center in the southern United States. A purposive sampling strategy was employed.[107] Participants were screened by the medical center coordinator regarding their cognitive and affective capabilities and independence in communication. Participants provided informed consent prior to the interview. Each participant received a $25 gift card as compensation.

The three focus group interviews followed a semi-structured group protocol that lasted approximately 75 minutes. Questions focused on: (1) personal learning challenges, (2) effective therapies and strategies, (3) the impact of hearing others' stories, (4) group-specific challenges and solutions, (5) building trust through shared expertise and partnership, and (6) motivational messages to encourage program engagement. Interviews were recorded and transcribed using Zoom web conferencing software.

Define Phase Procedures

In the Define phase, we conducted empathy mapping, developed learner personas, and refined our design principles based on synthesized insights.

Empathy Mapping. Empathy mapping was used to guide learner analysis and inform the design of the ePST intervention.[110] Procedures were grounded in data collected during empathy interviews with individuals with lived TBI experience and their care partners. Empathy mapping involved synthesizing participants' responses into four core domains ("Says," "Thinks," "Does," and "Feels") to foster understanding of their motivations, challenges, and learning preferences. This method allowed the research team to capture nuanced information about participants' cognitive, emotional, and behavioral experiences with learning and rehabilitation. A total of n = 9 empathy maps were created (see Supplementary Materials). These empathy maps were then used to generate a set of learner personas. They were also regularly referenced to inform subsequent design phases.

Persona Development. Personas are fictional, data-informed archetypes that represent individuals within the target population.[111] To create our personas, we first established the information that needed to be included in the personas, which fell into three broad categories: (1) demographic information, including key details regarding the persona's TBI; (2) goals, behavior, attitudes, and motivation; and (3) personal attributes, barriers, and facilitators. Following this, we summarized representative descriptors based on the information that we had synthesized in empathy maps. Although the majority of information used to create a persona tended to come primarily from a single empathy map, the design team would incorporate information from other empathy maps to provide diversity. Personas were then presented to the CAB and reviewed, after which the design team incorporated revisions. For example, initial designs included TBI severity; however, the CAB suggested that severity levels did not fully represent the nuanced characteristics of TBI and suggested the design team describe these characteristics with more detail. All CAB recommendations were incorporated into the personas, resulting in a final set of personas (n = 10) of individuals with TBI (see Supplementary Materials). These personas functioned as design anchors during subsequent development phases.

Refinement of Design Principles. A refined set of design principles was developed based on a structured empathy interview with five caregivers and providers. The session was transcribed using Zoom's automated tools and collaboratively reviewed by the first and last authors of this manuscript. The team employed a discussion-based analytic process to identify key insights grounded in the lived experiences of participants. Using the framework proposed by Kali,[112] the design team organized these insights into a three-tiered hierarchy of design principles. Each insight was articulated at the pragmatic level, reflecting actionable guidance relevant to the learning design. These pragmatic principles were then grouped into six broader meta-principles, such as accessibility, emotional support, motivation, personalization, cultural relevance, and evidence-based action. Where applicable, specific principles (e.g., interface features, content structures) were also identified to illustrate how the pragmatic principles would translate into concrete design decisions. The resulting set of design principles was subsequently reviewed during a structured CES session with the CAB. CAB members provided feedback on the clarity, relevance, and completeness of the principles, as well as alignment with community priorities and lived experience.

Develop Phase Procedures

In the Develop phase we engaged in design, planning, and prototyping to create a design proof that comprised a complete draft of all content, which was then reviewed by the CAB. Using insights and design principles established during the Define phase, the Develop phase focused on translating these into interactive prototypes through iterative design, community feedback, and structured refinement.

Community Engagement Studios. Structured CES sessions were used to elicit structured feedback from the CAB. The CES (n = 10) sessions focused on usability challenges, content clarity, and delivery preferences. Each CES session followed a structured facilitation protocol and was conducted virtually using Zoom web conferencing software. Sessions were 60–90 minutes in length and included between 6 and 8 CAB participants. A trained moderator guided discussion using a semi-structured guide. Discussion foci varied depending on which design artifacts were being reviewed, for example, accessibility of color palette, clarity of interface navigation, comprehensibility of content, length of lessons, etc. Participants were shown design artifacts (e.g., wireframes, functional prototypes) and asked to reflect on a range of issues such as clarity, relevance, and usability. These sessions were audio recorded and transcribed using Zoom. Following this, a research coordinator would review transcripts and notes and provide a report to the design team on identified design flaws or recommendations for improvements, which were then synthesized into actionable design recommendations.

Rapid Prototyping. Rapid prototyping is an iterative design approach that quickly develops and refines working models based on user feedback.[113] This approach was used to transform insights from the Define phase into working prototypes using a layered, iterative process. Initial design concepts were explored through low-fidelity mockups and storyboards. These early artifacts were then iteratively refined into medium- and high-fidelity prototypes. The team cycled quickly between design, feedback, and revision, emphasizing flexibility and responsiveness to user input.[113] These emerging designs were regularly reviewed during structured CES, allowing the team to address identified issues such as navigation, language complexity, and content pacing.

Deliver Phase Procedures

The Deliver phase involved iterative usability testing with individuals with lived TBI experience using think-aloud protocols, post-session surveys, and CAB feedback to guide ongoing refinements.

Usability Testing. Usability tests (n = 5) were conducted by a trained graduate student and a university professor usability expert. Testing followed a semi-structured, task-based research protocol followed by administration of the CAUSLT survey. Usability sessions were conducted, recorded, and transcribed using Zoom. Sessions lasted between 60 - 75 minutes. Each session began with an introduction to ePST and brief oral questions about participants' technology experience. Participants self-rated their digital proficiency, comfort, and confidence using eHealth tools for learning and health-related purposes. Participants then completed five structured usability tasks per session while thinking aloud and sharing their screens. Tasks assessed both technological usability (e.g., navigation, multimedia interaction) and pedagogical usability (e.g., clarity of content, microlearning structure). Four participants accessed the modules on mobile devices (iPhone n = 3; Android n = 1), with one using a Windows PC.

Following each usability session, participants completed the CAUSLT instrument[106], which evaluated ease of use, engagement, and learning support. Observers documented participant behavior during sessions and held debriefings to identify usability challenges. Combined with survey results and session transcripts, these insights informed development of a comprehensive usability report. The report was reviewed with the CAB, whose additional feedback guided refinements in areas such as voiceover quality, mobile navigation, and content clarity for cognitive accessibility.

Usability testing data were analyzed using an integrated approach that combined observational, survey, and efficiency metrics. After each session, think-aloud transcripts and observer notes were reviewed and discussed by two team members to identify key usability barriers, such as navigation issues, content clarity, or accessibility concerns. These issues were documented in a shared usability backlog to support iterative refinements. Participants' responses to CAUSLT were summarized using descriptive statistics, and disaggregated across the three instrument factors. Design flaws were prioritized using Nielsen's severity scale.[114] Efficiency data (i.e., task completion times, error rates) were extracted from session recordings to identify friction points in user flow. Findings were presented to the CAB and subsequently used to enact design improvements.

Results

Discover Phase Results

The Discover phase focused on establishing the foundational elements for ePST development through forming the CAB, conducting empathy interviews with key stakeholders, and establishing preliminary design principles. Results from these activities are presented below.

Composition of Community Advisory Board

The CAB consisted of 33 members, including individuals with lived experience, clinical and rehabilitation professionals, academic researchers, industry experts, and advocates. Table 2 presents the number of CAB members affiliated with each category. These are not mutually exclusive, and some individuals were represented in more than one group; that is, many CAB members self-identified with more than one category (e.g., a researcher who is also a care partner, or a clinician who is also from a minoritized group).

Table 2

Composition of CAB Members

Category	Composition	n
Academic researchers	PhD researchers (*n* = 12), Psychologists (*n* = 8), Educational technology experts (*n* = 2), Graduate students (*n* = 2)	24
Industry professionals	Software developer (*n* = 1), Software designers (*n* = 5)	6
Individuals with Lived Experience & Advocates	Individuals with TBI (*n* = 6), TBI care partners (*n* = 4), Disability advocates (*n* = 6)	16
Rehabilitation & Clinical Professionals	Occupational therapists (*n* = 4), Social workers (*n* = 3), Rehabilitation counselors (*n* = 3)	10
Individuals with physical disabilities	Blind (*n* = 1), Deaf (*n* = 1)	2
Individuals from minoritized groups	LGBTQIA+ (*n* = 4), Minoritized racial/ethnic groups (*n* = 6)	10

Preliminary Design Principles

A set of preliminary design principles was established to ensure alignment with the cognitive, emotional, and contextual needs of individuals with TBI. Drawing on results from prior research and CAB input, the principles emphasized accessibility, emotional resonance, clarity of messaging, and personalization. These principles served as the foundation for early prototypes and informed content structure, visual design, and engagement strategies used throughout development. While these preliminary principles guided the initial stages of design, they were subsequently expanded and structured into a comprehensive hierarchy during the Define phase. The full set of community-informed principles is presented in the Define Phase Results section.

Participant Demographics for Empathy Interviews

We recruited 14 participants (Table 3) for empathy interviews, including individuals with TBI (n = 9) and caregivers/providers (n = 5). Findings from these empathy interviews are presented in the Empathy Mapping Development and Persona Development sections below. Demographic information for empathy interview participants is presented in Table 3.

Table 3

Participant Demographics for Empathy Interviews

	Individuals with TBI	n	Caregivers and Providers	n
Race	Hispanic	1	Hispanic	1

	Caucasian/White	5	Asian	1
	African American	2	Caucasian/White	3
Age	30-39 (n = 4)	4	40-49	1
	40-49 (n = 3)	3	60-69	3
	50-59 (n = 1)	1	>70	1
Gender	Male	2	Female	5
	Female	7		

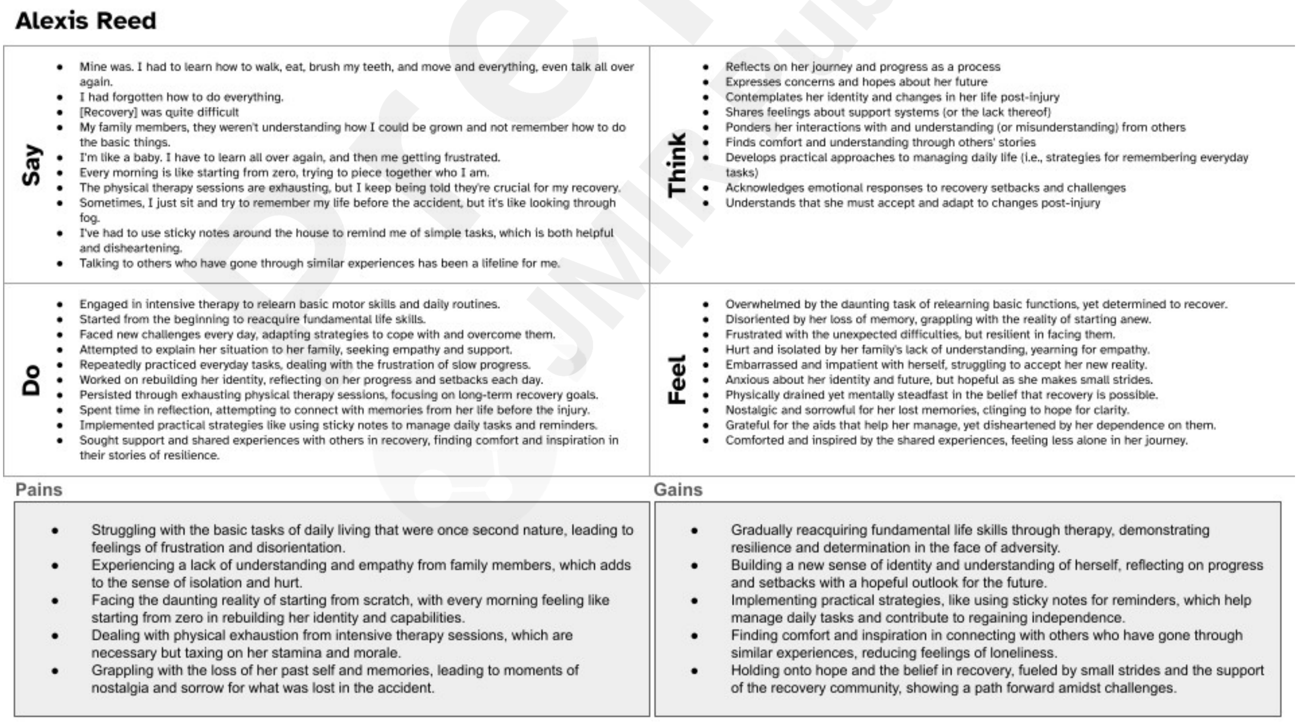
Define Phase Results

Empathy Maps

Empathy maps were created (n = 9), with each map included brief descriptors in categories like Says, Thinks, Feels, Does, Frustrations/Barriers, and Goals/Needs (Figure 5). Common patterns included memory issues, fear of failure, emotional overwhelm, and a strong desire for independence and support. Visual elements like sticky notes and color coding helped the design team identify cross-cutting needs and inform the development of learner personas and design priorities. Analysis of empathy maps revealed four key themes characterizing the post-TBI experience. Participants experienced frustration and disorientation with everyday tasks, loss of self-identity and nostalgia for pre-injury life, physical exhaustion from therapy that decreased motivation, and social isolation due to perceived lack of family understanding. In response, participants developed adaptive strategies including structured skill relearning through rehabilitation, memory aids such as sticky notes and phone apps, peer support networks to combat isolation, and gradual acceptance of limitations while building new identities through recovery. The full set of empathy maps is provided in the Supplementary Materials.

Figure 5

Sample empathy map (participant name is a pseudonym)

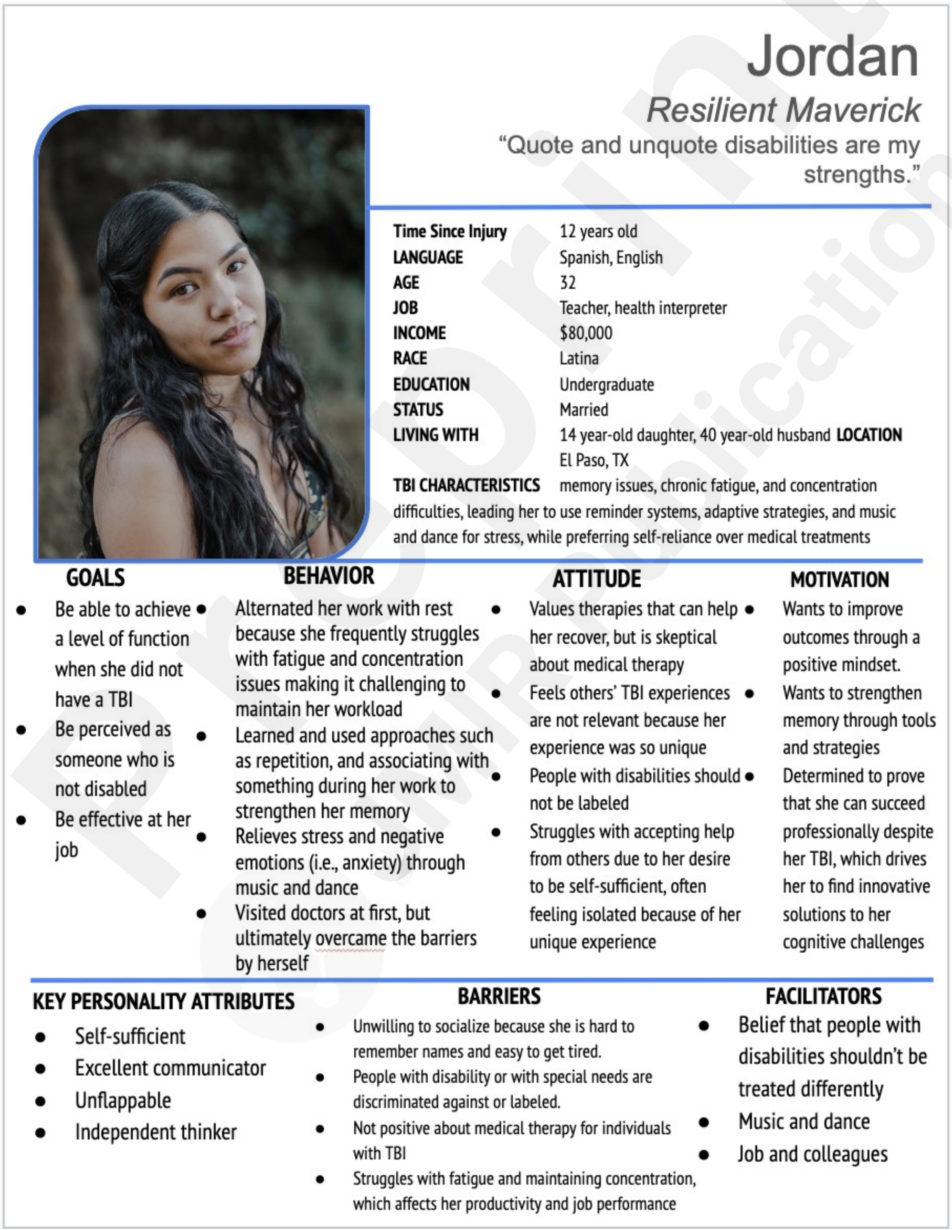


Personas

Based on the empathy maps, a set of personas (n = 10) were created to represent learner diversity and guide system design decisions. Personas highlighted varied life contexts, recovery journeys, and learning needs across individuals such as veterans, students, professionals, and retirees. Each persona reflected unique combinations of cognitive, emotional, and physical challenges, along with personal goals like regaining independence, improving memory, or reducing stigma. Common facilitators included family support, adaptive tools, storytelling, and professional guidance. Despite varied barriers ranging from aphasia to fatigue to discrimination, all personas demonstrated resilience and motivation to recover. For example, Jordan (Figure 6) is a Latina professional characterized as a "Resilient Maverick" who experiences memory issues, chronic fatigue, and concentration difficulties. She relies on reminder systems and adaptive strategies but prefers self-reliance over structured therapy and remains skeptical of formal medical interventions. Jordan's profile indicated that ePST needed customizable content delivery to accommodate users with differing levels of engagement with structured rehabilitation. The complete set of personas is provided in Appendix X.

Figure 6

Jordan's persona.



Refined Design Principles

Empathy interviews with caregivers and providers during the Define Phase generated design principles (n=14) that were then combined with the initial set of design principles that had been developed previously during the Discover Phase. To reduce redundancy and support practical implementation, the full set of design principles was reviewed for overlap and conceptual similarity. Related principles were collapsed and synthesized through design team discussion, resulting in a consolidated and non-redundant set. The final principles were then organized using Kali's[112] framework into a three-tier hierarchy (specific, pragmatic, and meta-principles). This process yielded a set of overarching meta-principles encompassing (1) accessibility, (2) emotional support, (3) engagement, (4) personalization, (5) credibility, and (6) evidence-based action (Table 4)

Table 4

Consolidated Design Principles for ePST Module Development

Meta-Principle	Pragmatic Principle	Specific Principles
1. Ensure Accessibility and Usability	Design for cognitive and physical inclusion	Use clear, concise, jargon-free language- Include closed captioning- Support mobile-first navigation- Design intuitive interaction patterns
	Support memory and comprehension	Reinforce key concepts with reminders and visual anchors- Use chunked content and repeated exposure
	Allow flexible engagement	Enable learners to proceed at their own pace- Allow pausing and resuming lessons easily
2. Support Emotional and Behavioral Needs	Encourage emotional regulation	Include calming activities (e.g., music, mindfulness cues)- Normalize behavioral variability in content
	Empathize with behavioral and communication challenges	Acknowledge and adapt for speech/behavioral limitations- Use neutral, non-judgmental tone
	Promote self-awareness and acceptance	Include prompts or reflection activities to build insight into strengths and limitations
3. Foster Motivation and Engagement	Use positive reinforcement	Integrate badges, rewards, and affirming feedback
	Emphasize goal setting and achievement	Provide explicit opportunities to set and track goals
	Provide regular feedback	Visual progress indicators- Summary pages at lesson/ module completion
4. Enable Personalized and Multimodal Learning	Use varied sensory inputs	Combine visuals, audio narration, and interactivity
	Allow for autonomy and independence	Design lessons that can be completed without facilitator support- Scaffold progressively to reduce reliance on help
	Tailor content for diverse learners	Include customizable avatars or pathways- Vary representation and examples by demographic relevance

5. Establish Credibility and Cultural Relevance	Include lived experience	Use testimonials from TBI survivors and care partners- Embed quotes and real-world scenarios
	Partner with trusted organizations	Reference TIRR, advocacy groups, and clinical partners in content
	Practice inclusive and representative design	Include diverse racial, ethnic, and gender identities- Adapt content for veterans and other priority subgroups
6. Ground Content in Evidence and Action	Communicate evidence accessibly	Present supporting research in simplified language or visuals- Avoid academic jargon
	Use motivating calls to action	End modules with clear next steps (e.g., “Enroll,” “Learn more”)- Include clickable links or guided follow-ups

Develop Phase Results

Through iterative rapid prototyping and ten Community Engagement Studio sessions, the design team developed a complete set of design artifacts progressing from initial storyboards to high-fidelity interactive prototypes (Figure 7). The prototyping process began with low-fidelity mockups that were systematically refined based on structured CAB feedback addressing usability challenges, content clarity, accessibility features, and delivery preferences. Key outputs included finalized lesson content with branching scenarios, interactive learning assessments, a cohesive visual design system, and functional prototypes demonstrating core user pathways. CES sessions yielded actionable design recommendations that were synthesized into iterative improvements, resulting in prototypes ready for comprehensive usability evaluation. Supporting documentation included revised design principles, structured feedback summaries from all CES sessions, and technical specifications for the mHealth platform architecture.

Figure 7

Evolution of ePST design elements from prototype to final product.

Deliver Phase Results

Participants

Five participants with TBI were recruited for usability testing using purposive sampling in accordance with Nielsen's (2000) heuristic for uncovering 80% of usability flaws. All participants sustained their injuries 11-20 years prior and reported varying levels of technology comfort and e-health platform experience. Participant demographics are presented in Table 5.

Table 5

Usability Study Participant Demographics

Partici-pant	Age	Gender	Race/ Ethnicity	Education	Employ-ment Status	Years Since Injury	Technology Experience
Leo	47	Male	Hispanic	High school	Permanent disability	17	Capable user, no e-health experience
Morgan	31	Female	White	Some college	Stay-at-home spouse	11	Capable user, occasional e-health use
Alexis	50	Female	Black	Bachelor's degree	Permanent disability	20	Experienced user, frequent e-health use
Riley	47	Male	White	Some college	Permanent disability	14	Experienced user, occasional e-health use
Emma	36	Female	White	Some college	Stay-at-home parent	13	Experienced user, occasional e-health use

Usability Performance Metrics

Participants demonstrated efficient task completion and strong content comprehension during usability testing. Performance metrics are summarized in Table 6.

Table 6

Usability Performance Results

Metric	Result
Efficiency Measures	
Average lesson completion time	11.47 minutes (SD = 5.28)
Average completion time - Module 2	10.50 minutes
Average completion time - Module 3	13.10 minutes
Time range (min-max)	4.6 - 21.42 minutes
Average tasks per user	22.8 tasks
Average tasks per lesson	11.4 tasks
Task completion rate	0.996 tasks per minute
Knowledge Assessment	

Overall accuracy	80% correct
Question 1 accuracy	80% correct
Question 2 accuracy	100% correct

CAUSLT Usability Assessment

Participants completed the Comprehensive Assessment of Usability for Learning Technologies (CAUSLT), which evaluates three dimensions of usability in educational technology using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). Results are presented in Table 7 and illustrated in Figure 8, Figure 9, and Figure 10.

Table 7

CAUSLT Usability Scores by STP Domain

Usability Dimension	M	SD	Min	Max
Technological Usability	4.06	0.95	3.50	5.00
Pedagogical Usability	4.34	0.77	3.43	5.00
Sociocultural Usability	4.13	0.87	3.00	5.00

Figure 8

Technological usability responses.

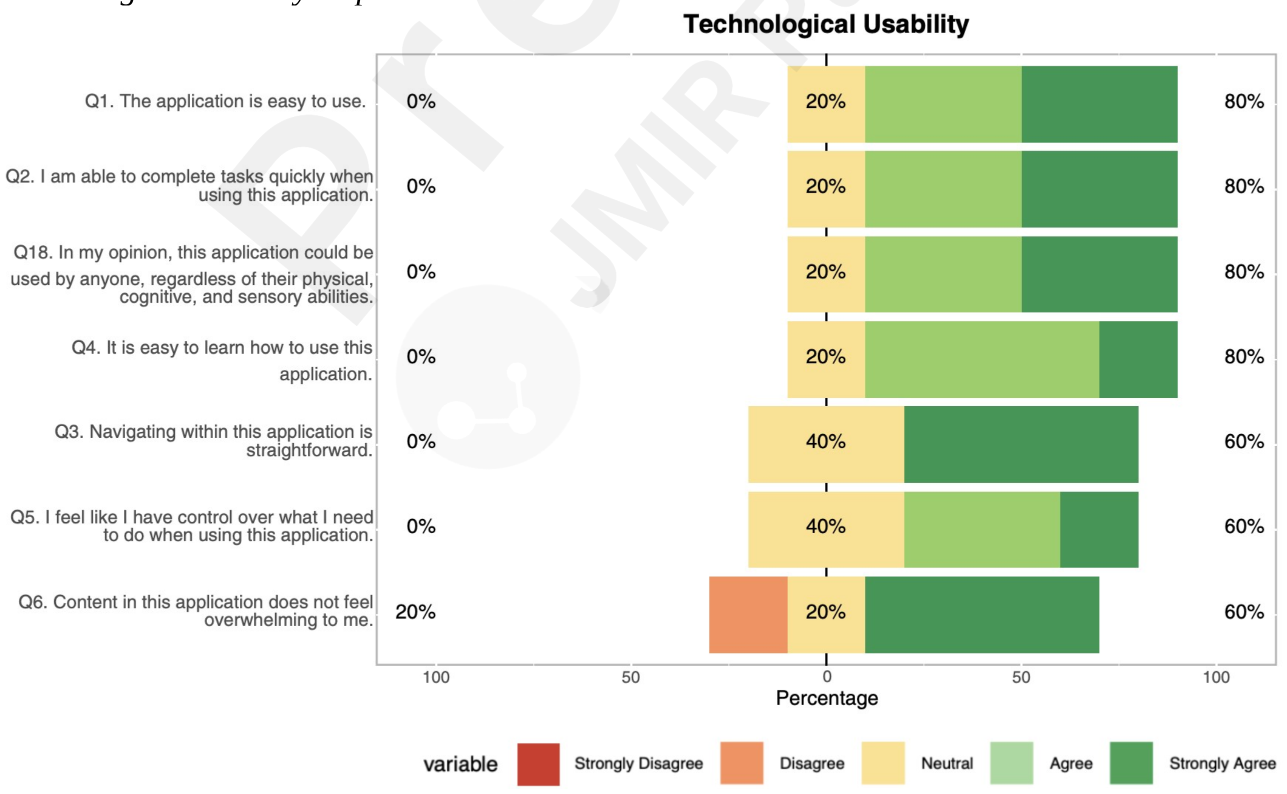


Figure 9

Pedagogical usability responses.

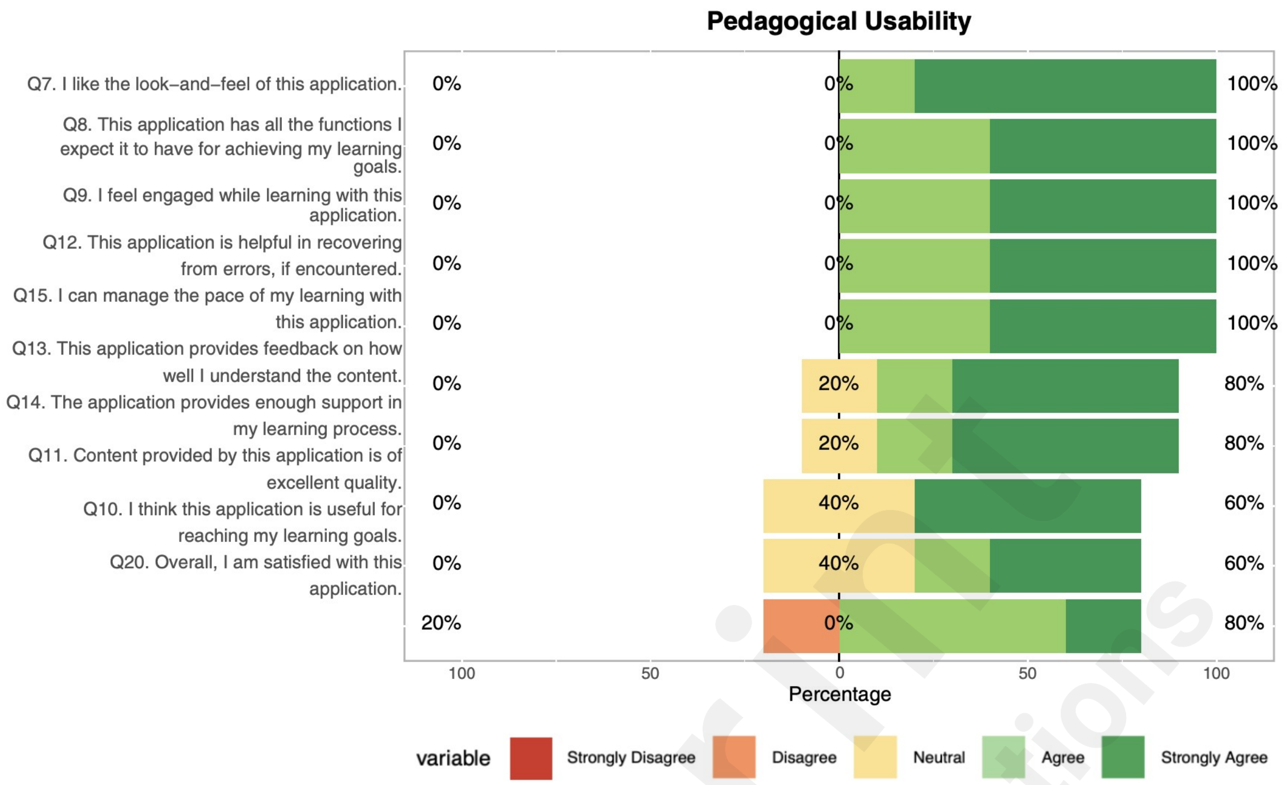
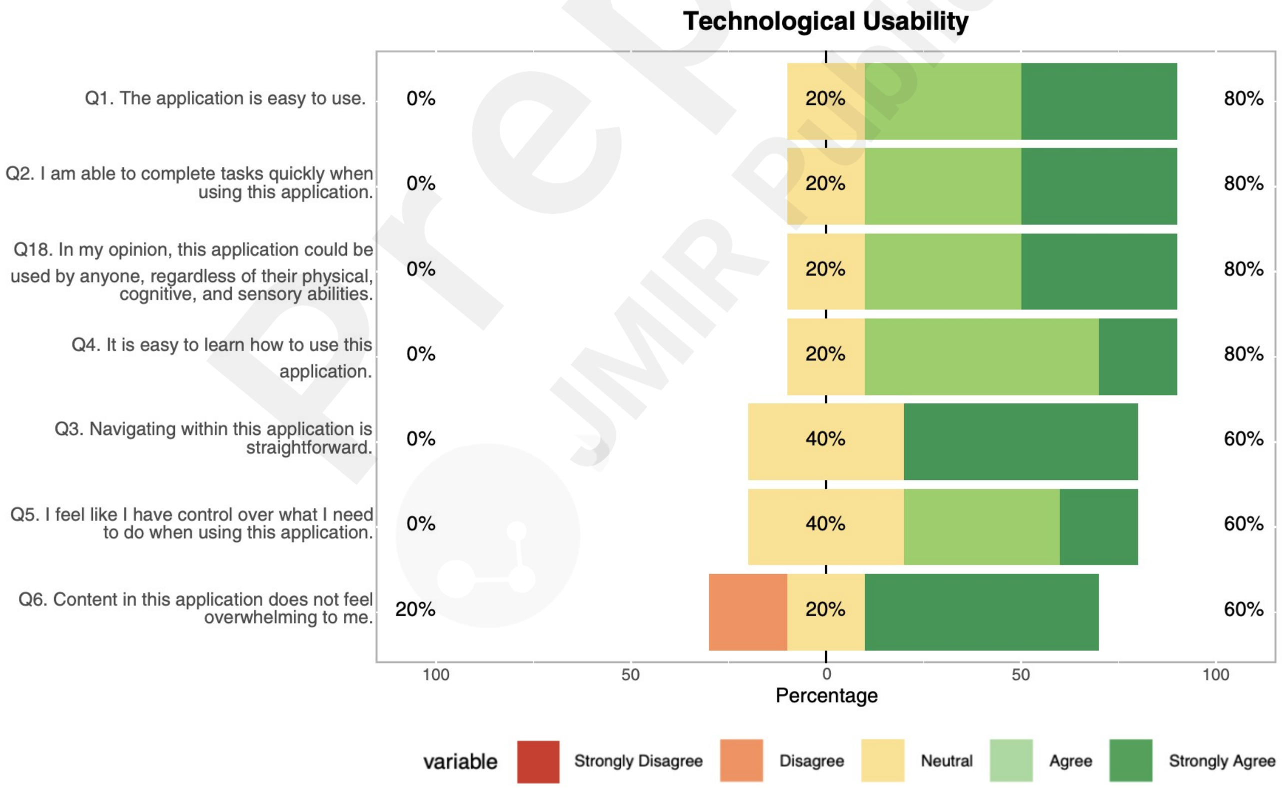


Figure 10

Sociocultural usability responses.



Pedagogical usability received the highest ratings (M = 4.34), with participants particularly valuing the application's look-and-feel (M = 4.8) and core learning functions including engagement, error recovery, and pace management (all M = 4.6). As shown in Figure 9, 100% of participants agreed or strongly agreed on items related to learning engagement, pacing, and functional adequacy, with only feedback-related items showing some neutral responses (20%).

Technological usability scored well overall (M = 4.06), with strongest ratings for ease of use, task completion speed, and accessibility across different abilities. Figure 8 shows 80% agreement across most technological items, though navigation and user control received slightly lower ratings (60% agreement), and content overwhelm was the only item receiving any disagreement (20%).

Sociocultural usability (M = 4.13) showed more variability, as illustrated in Figure 10. Participants were most confident about avoiding cultural prejudices (80% agreement), while social interaction opportunities and cross-demographic accessibility both received 60% agreement with higher levels of neutrality (40%), indicating potential areas for enhancement.

Key Usability Findings

Qualitative analysis of think-aloud transcripts and observation notes revealed both significant strengths and areas requiring refinement in ePST's usability. Content analysis identified patterns across participants' experiences that highlight the application's effectiveness in engaging users with TBI while revealing specific technical and interface challenges that impact user experience (Table 8). These findings provided actionable insights for iterative design improvements, which were incorporated between each usability testing session.

Table 8

Usability Strengths and Areas for Improvement

Usability Strengths	
Finding	**Description**
Intuitive Interface Design	Participants navigated the application easily and found interactive elements engaging. One participant described the storyline object as "pretty cool," indicating positive reception of multimedia components.
Effective Progress Tracking	Badge system and progress indicators were clearly understood and valued by users. Representative quote: "It looks like I've received one badge 1,2,3, and five more to go" and "It proves to me that I've done something."
Engaging Multimedia Elements	Varied voiceover tones, storytelling approach, and visual design elements received positive feedback. Participants appreciated the narrative-based learning style and accessibility features.
Successful Error Recovery	Adaptive feedback mechanisms enabled users to recover from errors in knowledge checks without significant frustration, maintaining learning continuity.
Areas for Improvement	
Finding	**Description**
Mobile Navigation Issues	Users experienced confusion with mobile interface controls and activity progression. Representative quotes: "I see a button on the bottom right that looks like a back arrow" and "Wait, where was 3.2?"
Content Comprehension	Some participants misunderstood instructions or content elements. One participant stated "Wait, this is not a question" when encountering a Storyline component.
Technical	Loading delays and playback issues disrupted user experience.

Performance	Representative quotes: "Oh, it has to load all over again" and "I can't see the whole screen" (mobile display problems).

Discussion

Key Findings and CBPR Mechanisms

This study demonstrates the feasibility of applying CBPR and user-centered design principles to develop rehabilitation technology for individuals with TBI. The systematic implementation of CBPR throughout ePST development produced specific design improvements through three primary mechanisms.

Iterative Community Feedback Enhanced Technical Usability

The CAB structure (33 diverse stakeholders) and structured CES sessions (n=10) enabled systematic integration of community input across development phases. CAUSLT scores averaged 87.3 out of 100, with pedagogical usability receiving the highest ratings. Participants completed lessons efficiently and achieved 80% accuracy on knowledge assessments, comparing favorably to cognitive rehabilitation intervention outcomes reported in systematic reviews.[115]

For example, empathy interviews with TBI survivors revealed specific cognitive load concerns that directly informed the microlearning approach (5-12 minute lessons) and progress tracking features. CAB feedback on early prototypes resulted in modification of the badge system design and influenced voiceover tone selection to reduce perceived condescension. These modifications were fundamental design decisions that addressed cognitive accessibility requirements identified through community input.[116] Importantly, usability issues identified through think-aloud protocols mapped directly to areas where CAB input had been limited or where technical constraints overrode community recommendations, suggesting that user involvement depth correlates with usability outcomes.[117]

Multi-Stakeholder Representation Identified Comprehensive Design Requirements

The CAB's composition systematically surfaced design considerations that single-stakeholder approaches typically overlook. Caregivers identified family involvement features, while clinicians contributed evidence-based content validation, and individuals with lived experience prioritized autonomy and stigma reduction elements. This multi-perspective input directly shaped the sociocultural usability features that scored highly in evaluation, particularly around cultural responsiveness and inclusive design.[118] Unlike traditional focus groups or surveys, the sustained CAB engagement spanning the entire development cycle allowed for iterative refinement based on evolving understanding of user needs. This depth of engagement appeared to contribute to high pedagogical usability scores and enabled authentic relationship-building rather than extractive consultation.[119]

TBI-Specific Technology Design Requirements Emerged

The usability evaluation revealed specific design requirements for cognitive rehabilitation technology that extend beyond general accessibility guidelines. Analysis of user interactions demonstrated that traditional e-learning design principles require significant adaptation for users with cognitive impairments, consistent with cognitive load theory applications in special populations.[120] The 21-minute range in task completion times (4.6-21.42 minutes) revealed that cognitive processing variability in TBI populations requires deliberate architectural choices rather than standard responsive design. Participants performed optimally with linear content progression and struggled with branching navigation structures, suggesting that linear content progression may reduce cognitive demands relative to complex navigation structures for users with executive function deficits.[121]

Navigation issues identified in think-aloud protocols were predominantly mobile-specific, with participants reporting confusion about interface cues ("I see a button on the bottom right that looks like a back arrow") and progression sequences. Technical performance issues disproportionately disrupted learning flow for participants with attention deficits, suggesting that cognitive rehabilitation technology requires higher technical performance standards than typical educational applications.[122] While participants appreciated multimedia elements and voiceover variety, content comprehension issues arose when instructional clarity was sacrificed for engagement. This indicates that TBI rehabilitation technology requires explicit signaling of content types and interaction expectations, with clarity taking precedence over novel interface design.[123]

Methodological Contributions

This study contributes methodological insights for implementing CBPR in rehabilitation technology development. The integration of CAB and CES structures with LXD principles demonstrates how participatory research can move beyond consultation to systematic co-design. The sustained engagement model (33 diverse stakeholders across the entire development cycle) provides a replicable framework for authentic community involvement, providing an actional alternative to extractive research practices. The mapping of community input to specific design modifications illustrates how participatory methods can produce measurable technical improvements, not merely ethical and accessibility compliance. Findings support the claim that CBPR's value extends beyond moral imperatives to offer practical advantages in rehabilitation technology effectiveness.

Limitations and Future Directions

Several limitations constrain the generalizability of our findings. Small samples, although common in user studies, limit representativeness of the broader TBI population, and self-reported measures may be subject to positive response bias in facilitated testing environments. Future evaluations should consider balancing participatory methods with objective metrics including time-on-task, error rates, and engagement logs for more accurate assessment. Further, some reported technical issues may reflect device-specific limitations rather than design flaws, indicating need for expanded cross-platform testing. In addition to this, the TBI-specific design features reported here may not transfer directly to other neurological populations, requiring investigation of how CBPR-based approaches perform across different rehabilitation contexts. While initial usability testing revealed strong satisfaction, sustainability of engagement remains unknown, suggesting a need for longitudinal metrics capturing retention, adherence, and health outcome durability.

A direction for future research is how participatory practices might influence long-term health outcomes and treatment adherence beyond usability metrics. Integration of adaptive technologies such as AI-driven personalization, voice-guided prompts, and real-time support could represent promising directions for accommodating cognitive variability in neurological populations. Additionally, examining the scalability of intensive CBPR approaches across diverse rehabilitation contexts (i.e., stroke recovery, spinal cord injury, etc.) could advance understanding of participatory design's broader applicability.

Conclusions

The current study demonstrates that systematic application of CBPR principles can produce both qualitative and quantitative improvements in rehabilitation technology usability through iterative community feedback, diverse stakeholder representation, and sustained engagement processes. The development of ePST illustrates how participatory methods can address specific design requirements for cognitive accessibility while maintaining high user satisfaction. Findings suggest that cognitive rehabilitation technology can benefit from specific design considerations including attention to cognitive load, clear navigation patterns, and explicit content signaling to address TBI-related challenges. This work provides further support for CBPR as a practical methodology in rehabilitation technology development, enhancing ethical research practices as well as technical outcomes. Investigation of long-term engagement sustainability and adaptive technology integration remains a direction for future research with promise for advancing understanding of how participatory approaches might contribute to more equitable, personalized, and effective rehabilitation interventions.

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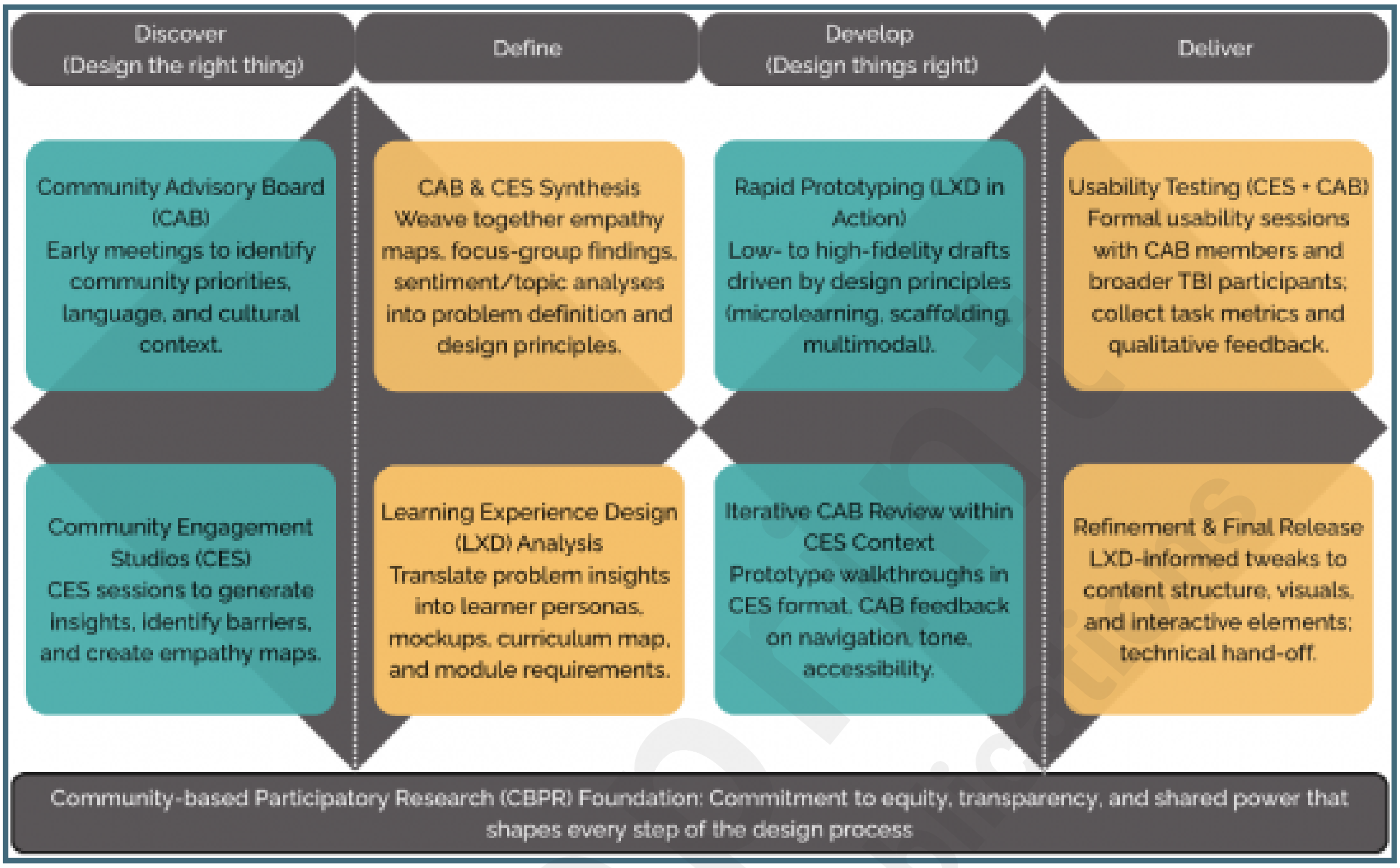
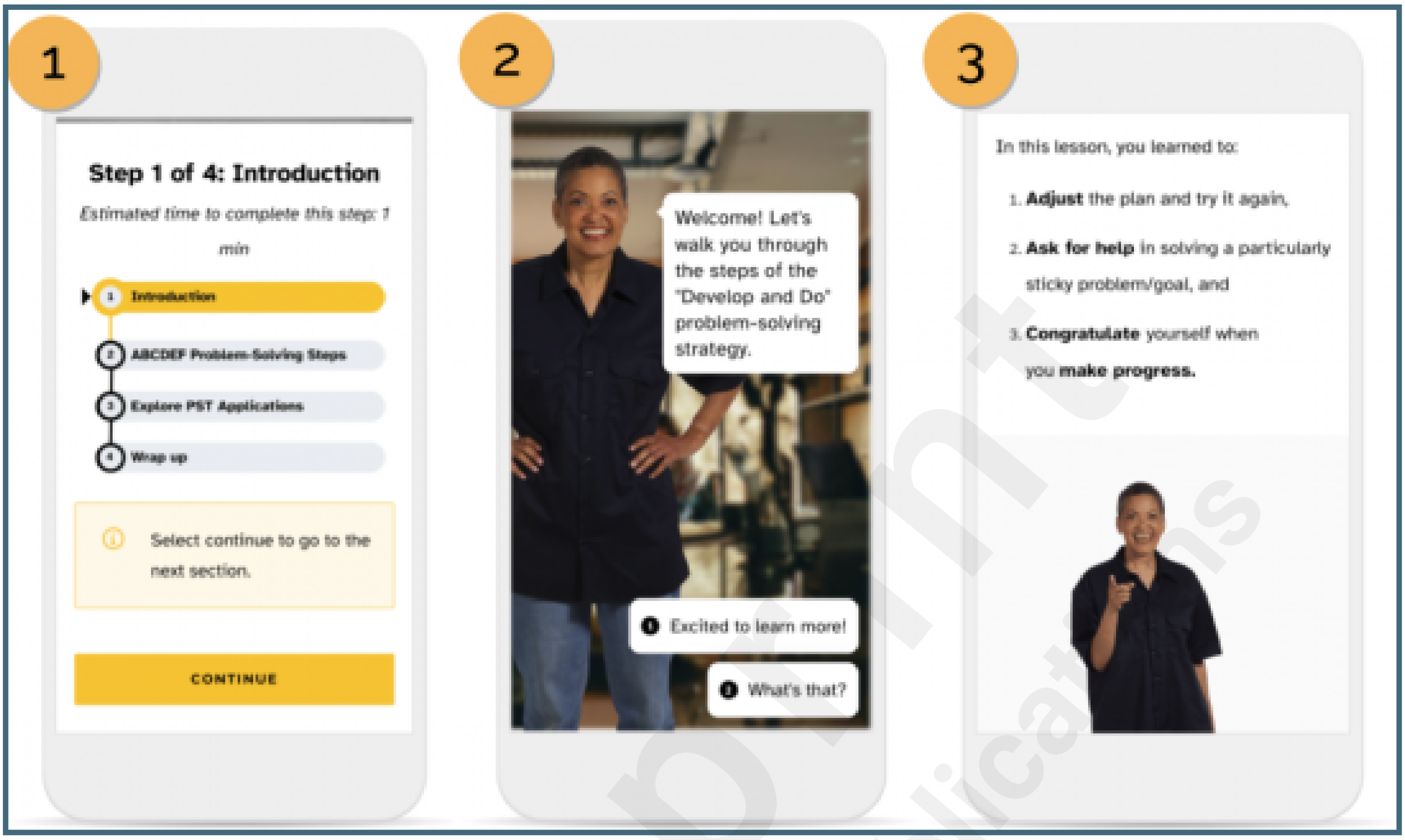
Supplementary Files

Figures

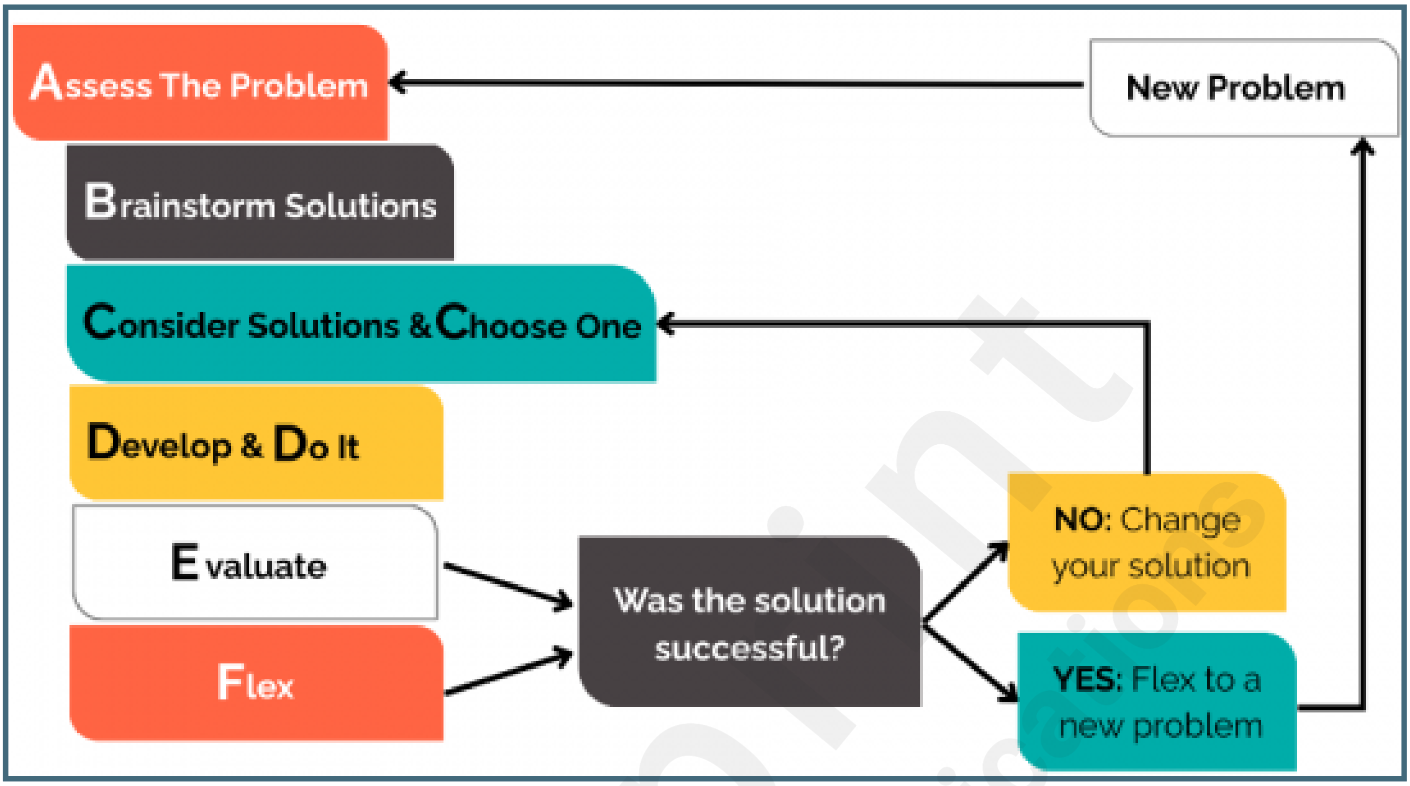
CBPR, CAB/CES, and LXD framework mapped across the Double-Diamond design cycle.



Screenshots of ePST, including (1) ePST Progress Tracker, (2) Coach Ruth, and (3) Reminders.

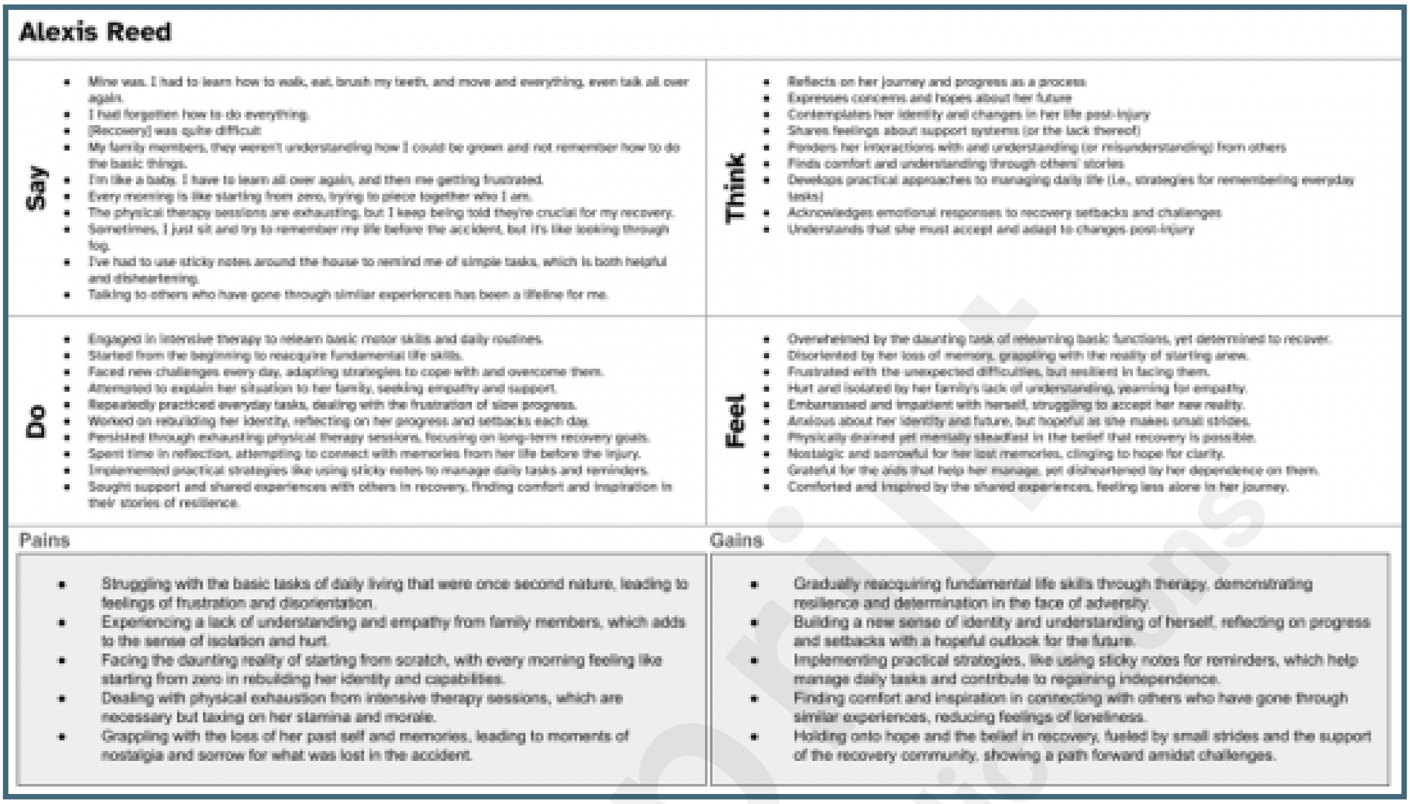


Problem-solving training strategy.

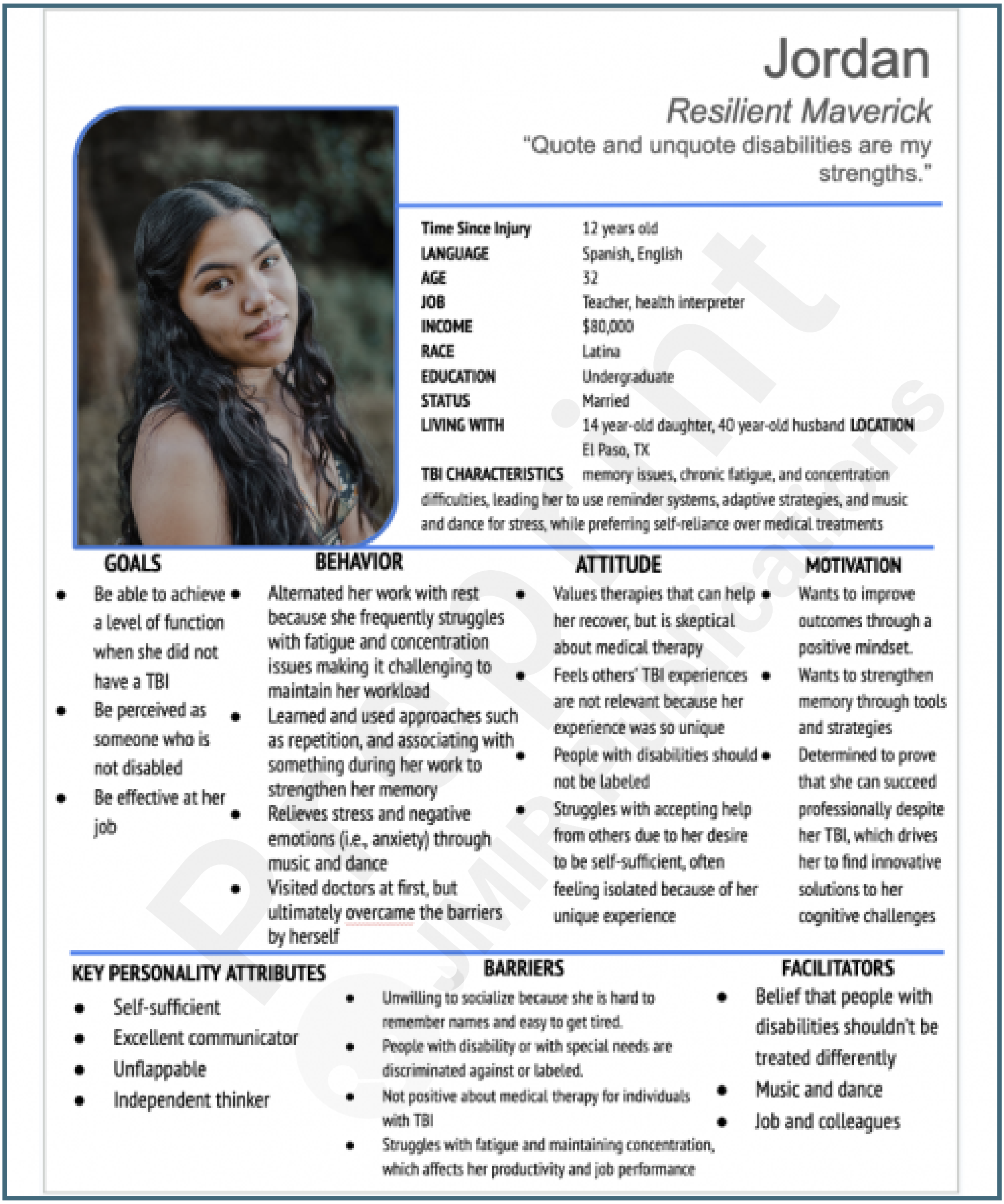


Example improvements to the badging component of modules.

Sample empathy map (participant name is a pseudonym).

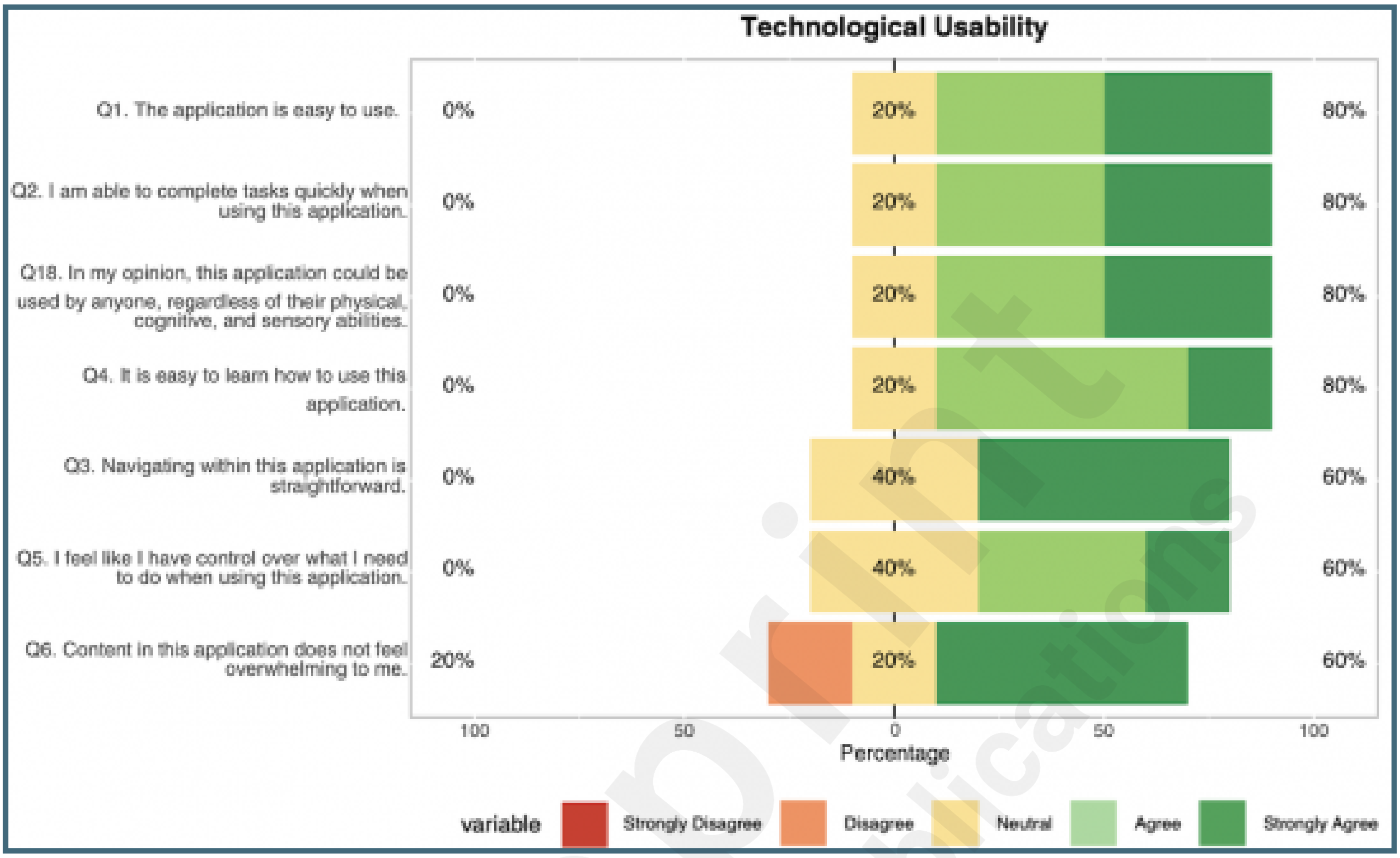


Jordan’s persona.

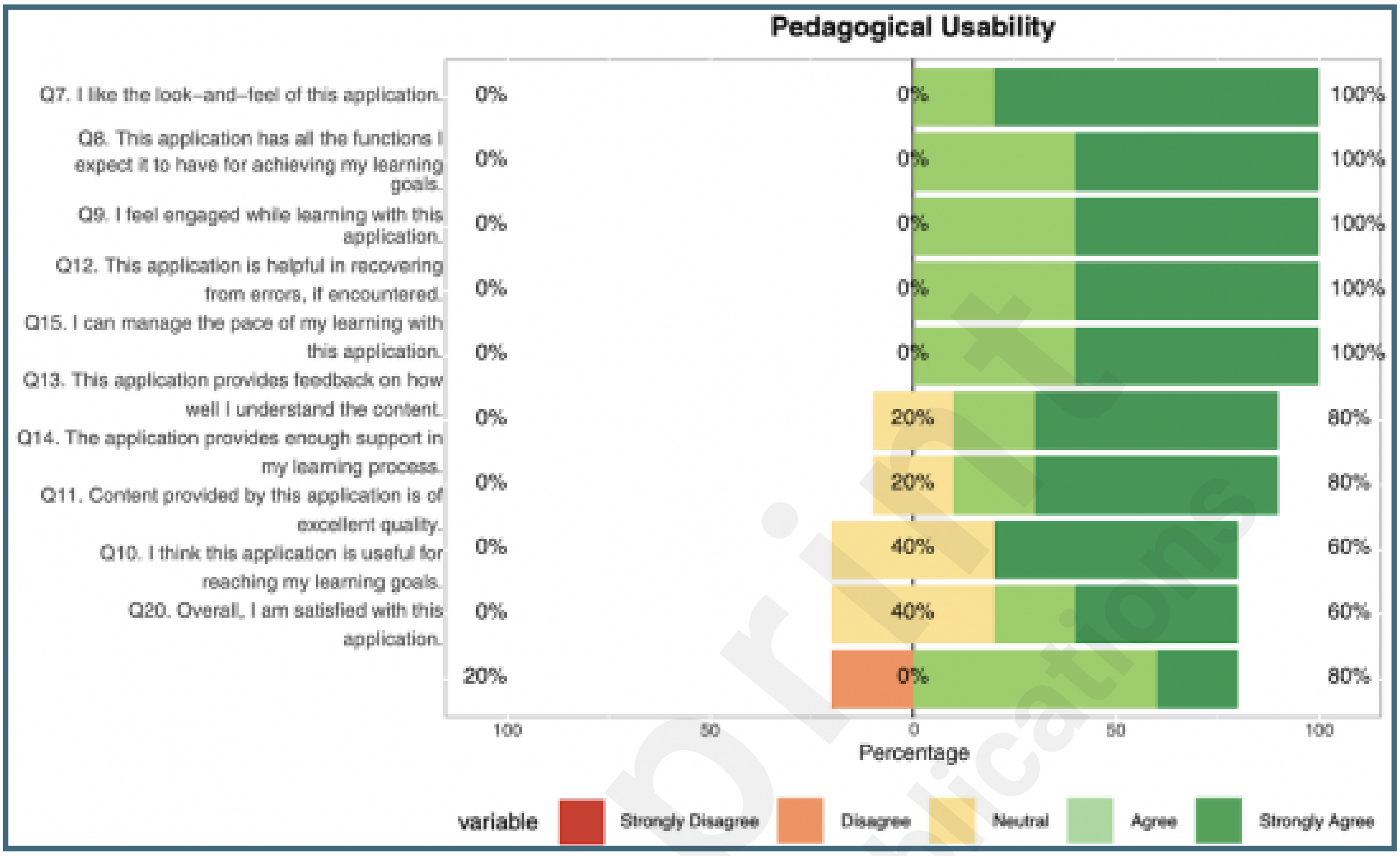


Evolution of ePST design elements from prototype to final product.

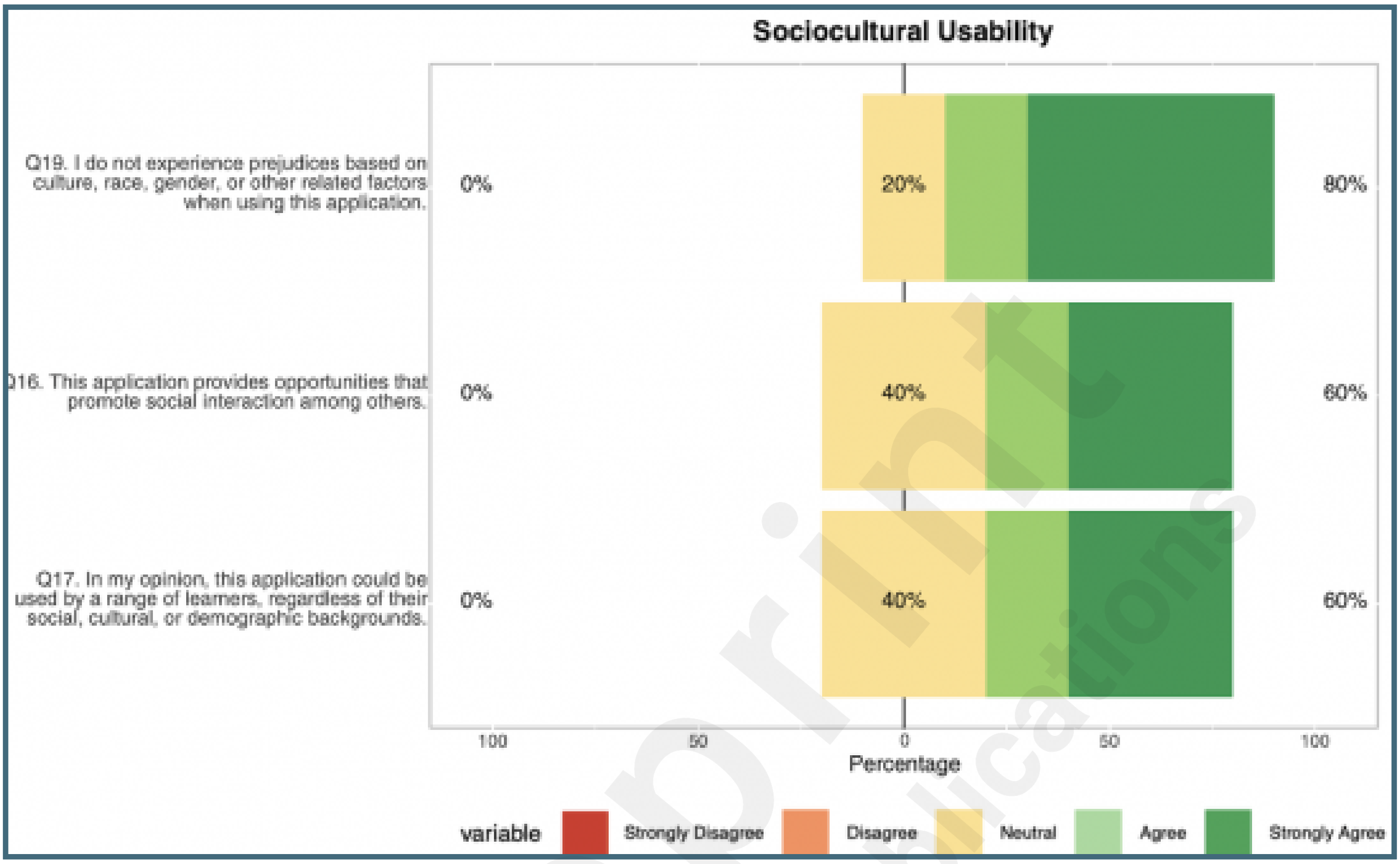
Technological usability responses.



Pedagogical usability responses.



Sociocultural usability responses.



Multimedia Appendixes

Alexis - persona 1.
URL: http://asset.jmir.pub/assets/020d48f0ae1fe01f06c77b1fd953d06a.png

Jordan - persona 2.
URL: http://asset.jmir.pub/assets/dbc2f70e154fb9b22a84c1c5cb520e2a.png

Taylor - persona 3.
URL: http://asset.jmir.pub/assets/200aacce468b2e0344f179e11698b636.png

Casey - persona 4.
URL: http://asset.jmir.pub/assets/727e6ee4acdf1870029353ba77dfe95a.png

Riley - persona 5.
URL: http://asset.jmir.pub/assets/f61e296153b2087f0a0d08de67e18050.png

Morgan - Persona 6.
URL: http://asset.jmir.pub/assets/0e695da35e22a04f0134dba21d8db110.png

Evelyn - persona 7.
URL: http://asset.jmir.pub/assets/83b1f54bac16d6ed794f3f30a1b42a7c.png

Marcus - persona 8.
URL: http://asset.jmir.pub/assets/4d92c4f837a0c7c31de8cb60a3daff85.png

Lila - persona 9.
URL: http://asset.jmir.pub/assets/a313fe309555430ebae59092e689a997.png

Carlos - persona 10.
URL: http://asset.jmir.pub/assets/070d820b4325a412b900d30c2ff48338.png

Alexis - empathy map 1.
URL: http://asset.jmir.pub/assets/aba9c7a9cf4ea263c40f19b9b6b66ccb.png

Jordan - empathy map 2.
URL: http://asset.jmir.pub/assets/7c9b6d71457025cc2a96b9c6c4ccebf2.png

Morgan - empathy map 3.
URL: http://asset.jmir.pub/assets/668070cf0da5191f7b6894e245b545b0.png

Casey - empathy map 4.
URL: http://asset.jmir.pub/assets/cd6a91575351595aaf9b980d99c58f82.png

Riley - empathy map 5.
URL: http://asset.jmir.pub/assets/8aef7a5f61eedb95a1af03be24411630.png

Taylor - empathy map 6.
URL: http://asset.jmir.pub/assets/bdda0d948a46d4fe99bf0b34e8e5d40a.png

Evelyn - empathy map 7.
URL: http://asset.jmir.pub/assets/49eaa461c93661c19517b45c7fb623a5.png

Marcus - empathy map 8.
URL: http://asset.jmir.pub/assets/c9330b3a71e6bdb9643e12cda6c8a347.png

Lila - empathy map 9.
URL: http://asset.jmir.pub/assets/678de7281db472b71a2f498620b18801.png

TOC/Feature image for homepages

ePST landing page.