THESIS TITLE

Design Exploration for the Clinical Workflow of a Gamified Pediatric Rehabilitation Platform

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Abstract

Pediatric neurodevelopmental disorders (NDDs) requiring upper-limb rehabilitation typically necessitate sustained patient engagement, yet traditional interventions may present challenges in adequately accommodating diversity in patients' cognitive and motor ability. While gamification supports rehabilitation engagement, existing platforms often lack sufficient cognitive adaptivity, which may limit therapeutic efficacy.

Within this context, this thesis explores design considerations for PhiCube, a bilateral robotic rehabilitation platform developed by Rehabilia Technologies, targeting children with NDDs. In fact, in clinical settings, therapists often guide patients through "gamified" training. This study identifies opportunities to reduce therapists' learning burden, lower children's cognitive demands, and support clinical decisions.

A multidisciplinary research approach integrates design principles for cognitive and motor diversity with empirical analysis, including stakeholder interviews, competitor benchmarking, and clinical workflow exploration. Literature research examines adherence challenges in pediatric rehabilitation, the clinical outcomes and limitations of gamification, and strategies for enhancing therapeutic engagement and accessibility.

Findings show PhiCube incorporates valuable features including adaptive training and performance tracking, but gaps exist; in particular, unclear mapping between games and therapeutic targets, under-prioritized adjustable parameters, and insufficiently defined intervention goals.

Proposed design interventions target different areas: enhancing therapist usability through improved information architecture; and assisting clinical decision-making through hierarchical parameter adjustment. These actions will even allow to achieve the reducing children's cognitive demands through minimal interfaces and progressive complexity.

This work demonstrates that cognitive accessibility alongside motor adaptation is essential for engagement and therapeutic outcomes. Limitations include focus on clinical scenarios and cognitive accessibility, suggesting future home-based and broader accessibility research.

Keywords: Human-Robot Interaction; Robotic Rehabilitation; Pediatric Rehabilitation; Gamification; Cognitive Load; Cognitive Accessibility; Adaptive Interfaces; Usability; Information Architecture.

Sommario

I disturbi neuroevolutivi pediatrici (NDDs) che richiedono riabilitazione dell'arto superiore necessitano di un coinvolgimento prolungato del paziente; tuttavia, gli interventi tradizionali spesso non si adattano adeguatamente alla diversità cognitiva e motoria. Sebbene la gamification favorisca l'engagement, molte piattaforme presentano limitata adattività cognitiva, riducendo potenzialmente l'efficacia terapeutica.

All'interno di questo contesto, questo Lavoro di tesi analizza le considerazioni progettuali per PhiCube, una piattaforma robotica bilaterale sviluppata da Rehabilia Technologies per bambini con NDDs. In ambito clinico, i terapisti guidano i pazienti in percorsi "gamificati"; lo studio individua opportunità per ridurre il carico cognitivo dei bambini, alleggerire l'onere di apprendimento dei terapisti e supportare il processo decisionale clinico.

L'approccio di ricerca multidisciplinare integra i principi del design per la diversità cognitiva e motoria con un'analisi empirica che comprende interviste agli stakeholder, benchmarking dei competitor ed esplorazione dei flussi di lavoro clinici. La revisione della letteratura esamina le sfide legate all'aderenza nella riabilitazione pediatrica, gli esiti clinici e i limiti della gamification, nonché le strategie per migliorare l'engagement terapeutico e l'accessibilità.

I risultati evidenziano diversi punti di forza della soluzione robotica, come l'allenamento adattivo e il monitoraggio delle prestazioni, ma anche criticità: mappatura poco chiara tra giochi e obiettivi terapeutici, parametri regolabili non adeguatamente prioritizzati e obiettivi di intervento insufficientemente definiti.

Le proposte progettuali mirano a migliorare l'architettura informativa per i terapisti e strutturare gerarchicamente la regolazione dei parametri clinici. Queste azioni permetteranno persino di ridurre il carico cognitivo dei bambini attraverso interfacce minimali e una complessità progressiva.

Lo studio sottolinea come l'accessibilità cognitiva, insieme all'adattamento motorio, sia essenziale per favorire engagement ed esiti terapeutici, suggerendo future ricerche in contesti domiciliari.

Parole Chiave: Interazione Uomo-Robot; Riabilitazione Robotica; Riabilitazione Pediatrica; Gamification; Carico Cognitivo; Accessibilità Cognitiva; Interfacce Adattive; Usabilità; Architettura dell'Informazione.

Chapter 1. Background

1.1 Introduction

In pediatric motor rehabilitation, interventions typically involve long-term, structured training aimed at improving functional movement capacity (Maalej et al., 2019). During such interventions, it is also necessary to consider the child's comprehension of tasks, the dynamic adaptability of exercises, and the sustained engagement of the patient throughout the process.

Neurodevelopmental Disorders (NDDs) represent a complex subset of neurological conditions that affect the structure and function of the central and peripheral nervous systems. These disorders often result in multidimensional impairments across motor, cognitive, and emotional domains. Typical symptoms of neurological disorders include pain, motor dysfunction, cognitive challenges, and sensory abnormalities (Cleveland Clinic, 2024). In the clinical setting, addressing these symptoms requires a multidisciplinary approach where the collaborative effort of the patient, the therapist, and the technology is essential.

Existing research highlights that rehabilitation strategies centered on repetitive and task-specific practice demonstrate positive effects in neurological motor rehabilitation (Fernández-González *et al.*, 2024). However, maintaining high-intensity repetition in children can be intrinsically difficult. Consequently, rehabilitation devices that provide controlled repetition, real-time feedback, and gamification mechanisms have been utilized within rehabilitation centers. By embedding therapeutic goals into interactive play, these systems aim to bridge the gap between repetitive clinical requirements and the patient's intrinsic motivation (Tatla et al., 2013).

1.2 Project Context

PhiCube, featuring a modular bilateral robotic device and its accompanying software is developed by Rehabilia Technologies (2026) – a spin-off company of the Istituto di Sistemi e Tecnologie Industriali Intelligenti per il Manifatturiero Avanzato (STIIMA), National Research Counsil (CNR). It adopts a neuromotor impairment–driven logic rather than being limited to a single diagnostic category. This orientation suggests potential applicability across neurodevelopmental conditions involving upper-limb motor impairment and visuomotor integration difficulties, including Cerebral Palsy (CP) and Developmental Coordination Disorder (DCD).

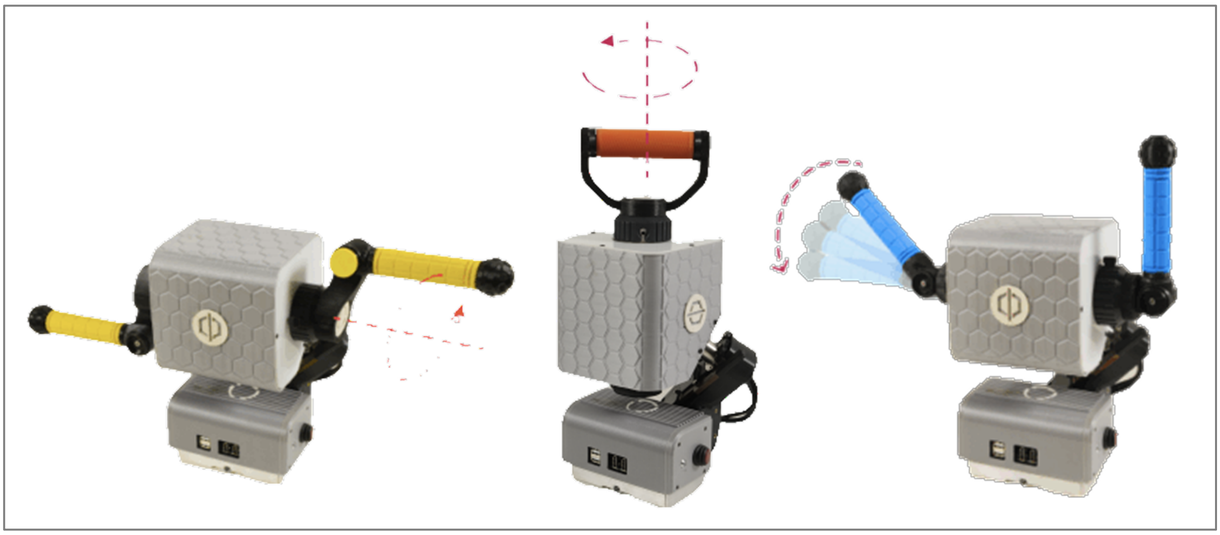

Figure 1: Part of the PhiCube hardware system (Rehabilia Technologies, 2026).

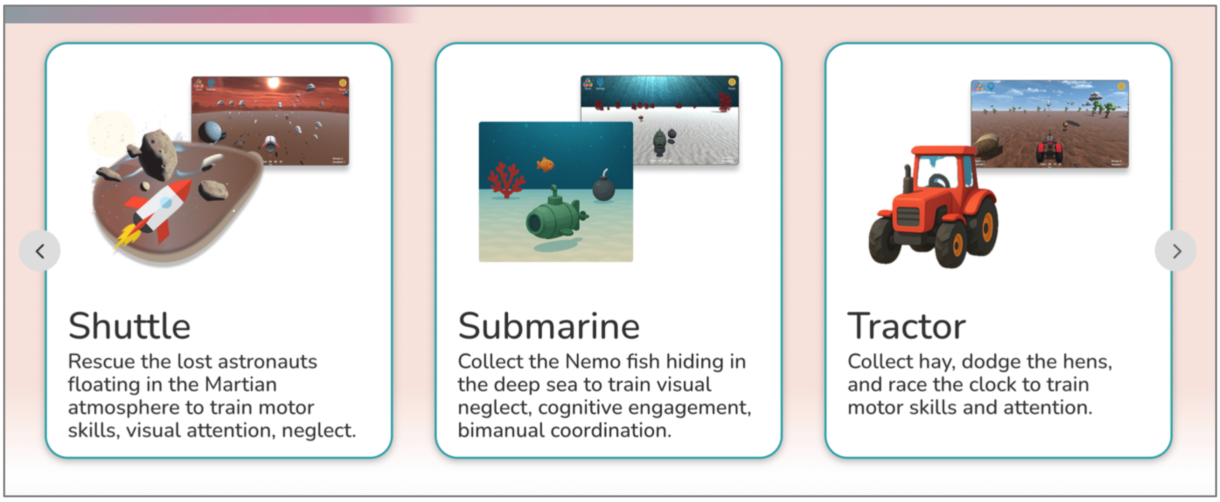

Figure 2: Examples of PhiCube gamified training interfaces (Rehabilia Technologies, 2026).

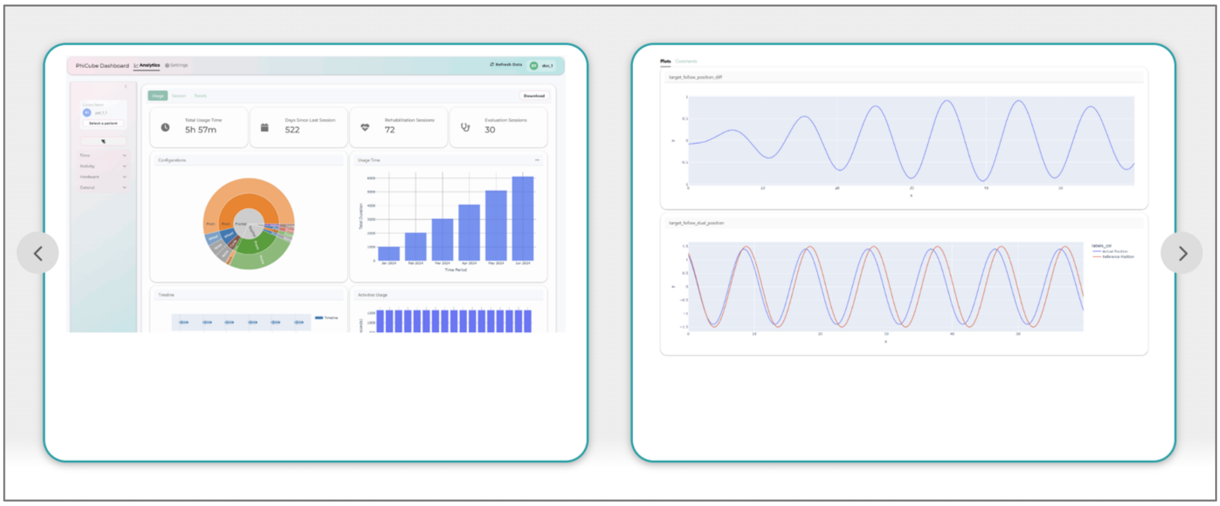

Figure 3: Part of the PhiCube therapist analytics dashboard (Rehabilia Technologies, 2026).

The core of the PhiCube system comprises a motorized central unit, interchangeable multi-sized handles, and a supporting software platform (see figures 1-3). Its patented and portable hardware supports multiple training modalities—including passive, assistive, active, and resistive modes—with adjustable parameters to accommodate varying motor functions. By combining force-feedback technology with bilateral coordination training, the hardware translates physical movements into digital gameplay.

The accompanying software plays an important role in embedding therapeutic movements within meaningful, adaptive activities. Rather than seeking to remediate potential cognitive impairment directly, the platform aims to enhance cognitive accessibility and sustained patient engagement through motor-learning tasks. Through this structure, the system aims to support motor relearning while accommodating individual differences in both motor and cognitive abilities. Specifically, the software integrates therapist-driven tools for personalizing training programs and visualization interfaces for monitoring rehabilitation progress.

While the vision of PhiCube includes a continuum of care that could extend from supervised clinical rehabilitation to home-based settings, the design exploration conducted in this thesis focuses specifically on clinical scenarios. Under this scope, the device is utilized under the direct guidance of professional therapists. Consequently, clinical therapists are identified as the central users, guiding and supervising the pediatric patients to perform motor bilateral therapies. The proposed software interventions prioritize supporting this professional-led therapeutic interaction, focusing on exploring the rehabilitation workflow within the clinical environment.

1.3 Objective

The study aims to synthesize design insights through theoretical frameworks and empirical investigation, identifying opportunities to provide practical implications for the continued design of the PhiCube gamified pediatric rehabilitation platform. Specifically, the design practice aims to explore the improvement opportunities in the clinical scenarios of PhiCube usage, focusing on its clinical workflow.

1.4 Methodology

This study adopts a qualitative, design-focused research methodology to identify the design and improvement opportunities for the PhiCube platform and derive design implications for therapist-oriented interfaces in clinical pediatric rehabilitation settings. The methodology is structured in four interconnected phases.

1.4.1 Theoretical Foundation

Theoretical research was conducted across three core domains: (1) adherence and motivation challenges in pediatric rehabilitation, (2) gamification strategies, including their clinical outcomes and limitations in therapeutic settings, and (3) design principles for accommodating cognitive, literacy, and motor ability diversity. These theoretical frameworks were synthesized to establish design considerations for accessible and engaging gamified rehabilitation platforms.

1.4.2 Empirical Analysis

The empirical analysis was conducted to ground the research in clinical practice and existing system conditions. The study first involved a thematic analysis of qualitative research materials provided by Rehabilia Technologies. These structured interview records from neuropsychiatrists, therapists, and clinic managers were analyzed to identify recurring challenges and misalignments between existing gamified designs and the specific cognitive and therapeutic requirements of pediatric users. This process provided the grounded evidence necessary to define the functional requirements for the gamified rehabilitation platform.

Based on these stakeholder insights, an initial review of the PhiCube platform was carried out to understand its current hardware and software characteristics, with a focus on therapist-oriented workflows including game selection, parameter configuration, and clinical documentation. Subsequently, competitor benchmarking was performed to situate PhiCube within existing clinical rehabilitation tools. The selection of reference systems, including ArmMotus™ M2 and CycleMotus™, was guided by three criteria: functional relevance in supporting upper-limb neuromotor training, the integration of physical hardware with a digital gamified interface, and observed clinical presence. By focusing on devices commonly encountered in rehabilitation centers, the benchmark aims to provide an initial analysis reflecting the current technological landscape in which these clinical tools are deployed. This approach may help identify potential improvement and differentiation opportunities for PhiCube, particularly regarding accessibility and user engagement.

1.4.3 Synthesis and Definition

Findings from theoretical and empirical sources were synthesized to develop therapist persona (Dr. Elena) representing the primary clinical user, capturing her goals, pain points, and workflow context. A problem statement was formulated to frame the potential design challenges related to clinical deployment and workflow integration of the platform. A feature prioritization matrix was then used to scope potential design interventions into Must-have, Should-have, Could-have, and Won't-have categories. This process helped focus the design exploration on clinically essential functions and workflow-related opportunities.

1.4.4 Design and Iteration

Targeting the prioritized requirements, design concepts were developed for therapist-oriented interfaces, with a focus on game-purpose clarity, session templating, and parameter adjustment. The information architecture for clinical workflow, informed by prior user, platform, and benchmark insights, was refined through card sorting and tree testing methods. These were followed by the development of initial interface prototypes. A future validation strategy involving usability testing with clinical therapists was also considered, with proposed questions intended to support further interface prototype refinement and clinical alignment.

The design methodology prioritizes depth over breadth by focusing specifically on clinical scenarios where therapists act as primary users. While this study acknowledges the value for home-based extension, the design practice and functional requirements are centered on clinical rehabilitation scenarios. Home-based application is identified as a future research scenario only.

Chapter 2. Literature Research

2.1 Adherence and Motivation Challenges in Rehabilitation

The effectiveness of physical rehabilitation depends heavily on sustained exercise routines. While clinical sessions provide professional supervision, the limited frequency of these sessions often makes it difficult for patients to achieve the volume of motor repetitions necessary for recovery. Among the factors influencing rehabilitation outcomes, patient adherence—defined as the extent to which individuals follow prescribed therapeutic recommendations—has been identified as particularly influential, yet difficult to predict (Jack *et al.*, 2010). In pediatric populations, the challenge is further shaped by the difficulty children experience in sustaining motivation during repetitive therapeutic activities. These challenges highlight the need for more engaging clinical systems that can establish strong adherence early in the treatment process.

Motivation also plays an important role in rehabilitation by facilitating the neuroplastic processes underlying motor learning (Tatla *et al.*, 2013). Systematic reviews of gamified interventions in pediatric neuromotor rehabilitation report improvements across domains such as balance, strength, coordination, functional abilities, and family satisfaction with treatment (Fernández-González *et al.*, 2024). These findings indicate that gamification may contribute to both behavioral engagement and clinically relevant progress.

2.2 Gamification in Pediatric Rehabilitation

2.2.1 Gamification Strategy

While physical rehabilitation typically requires intensive and repetitive exercise programs to restore motor function and improve quality of life, maintaining consistent engagement with rehabilitation programs remains a persistent challenge across healthcare contexts. Such problem is particularly pronounced among children and adolescents, who demonstrate higher dropout risks compared to adult populations. Unlike adults who comprehend the long-term benefits of therapeutic exercises, young patients often lack the intrinsic motivation to persist with monotonous rehabilitation tasks without short-term rewards or engaging experiences (Gómez-Portes *et al.*, 2020).

Multiple factors contribute to poor adherence in pediatric rehabilitation. Psychological factors include low self-efficacy—patient's beliefs about their ability to successfully complete rehabilitation tasks—which has been strongly linked with reduced adherence in orthopedic and musculoskeletal populations (Argent, Daly and Caulfield, 2018). When patients perceive that outcomes depend primarily on external factors rather than their own efforts, they demonstrate lower commitment to therapeutic activities. Social factors also play a critical role, as insufficient support from family members, friends, and therapists can negatively impact patient's sustained engagement with rehabilitation programs.

In response to these challenges, gamification has been explored as a strategy for supporting motivation and engagement in rehabilitation. By integrating selected game design elements into therapeutic exercises, healthcare professionals aim to encourage more consistent and intensive participation (Lister *et al.*, 2014). This approach has been applied in pediatric neuromotor rehabilitation, where game-based activities are used to support engagement during therapy sessions. Previous studies also suggest that gamified exercises may be perceived as more enjoyable by children and can be associated with positive rehabilitation outcomes (van der Kooij *et al.*, 2019).

As gamification techniques have emerged as a promising strategy to address these motivation challenges, by transforming repetitive therapeutic exercises into engaging game-based experiences, rehabilitation systems can potentially encourage patient engagement while maintaining therapeutic efficacy (Gómez-Portes *et al.*, 2020).

2.2.2 Game-Based Intervention Outcomes and Limitations

A growing body of evidence supports the integration of games used with serious purposes in pediatric rehabilitation interventions. Lopes *et al.* (2018) conducted a systematic review examining 16 studies involving 203 participants with cerebral palsy. The review found that the majority of studies reported positive therapeutic gains when games were incorporated into intervention protocols, primarily targeting motor function improvements including arm function, hand coordination, balance, gait function, and postural control. Specifically, all studies documented high levels of compliance, motivation, and engagement among young patients.

It is worth to note that despite these encouraging findings, Lopes *et al.* (2018) emphasized that games should complement rather than replace conventional therapies. The therapeutic gains observed were often modest and varied across different measurement instruments, suggesting that standardized clinical assessments may not fully capture functional improvements perceived by therapists and family members in daily life contexts.

While both commercial and custom-designed games have been applied in therapeutic contexts, adapting game-based systems to the cognitive abilities of individual pediatric patients remains challenging (Fernández-González *et al.*, 2024). In particularly, many existing systems do not sufficiently account for children's cognitive developmental stages and information processing capacities, potentially limiting accessibility and effectiveness for users with diverse needs.

A systematic mapping study by Gómez-Portes *et al.* (2020) further revealed critical gaps in current rehabilitation systems for young people. Their analysis indicated that few existing systems adequately support the personalization of exergame features to accommodate individual patient needs and pathological specificities. Moreover, the study identified a notable absence of methodological frameworks to guide the design and implementation of therapeutic exergames, and limited adoption of co-creative design approaches involving multiple stakeholders—including patients, families, and rehabilitation professionals.

While important limitations remain in the implementation of gamified rehabilitation platforms, given the demonstrated potential of gamification to support rehabilitation outcomes (Moulaei *et al.*, 2023), addressing the design challenges of aligning the gamified training tasks with rehabilitation goals, supporting the personalized accommodation of patient needs, and adapting to individual patient abilities are essential for realizing the therapeutic value of game-based rehabilitation platforms.

2.2.3 Difficulty Adaptation in Gamified Rehabilitation

Maintaining an optimal balance between task challenge and patient skill is a foundational requirement for sustained engagement in pediatric rehabilitation. Within the context of game-based interventions, this balance is often addressed through adaptive games that dynamically adjust to the patient's performance.

Hamari *et al.* (2016) empirically investigated the relationships among challenge, skill, engagement, immersion, and learning outcomes in physics-based educational video games. Their analysis revealed that challenge and skill balance predicted both engagement and immersion, which in turn mediated the effects on perceived learning. This challenge-skill dynamic indicates that as players' skills develop through practice, progressively higher challenges are required, thereby increasing competencies over time.

For pediatric rehabilitation games in particular, adaptive design approaches must address some critical needs. For example, three critical requirements were identified by Ben Itzhak *et al.* (2023) in the context of children with cerebral visual impairment. First, games should support learners' diverse abilities and difficulties, tailored to individual needs. Second, since learners' skills are dynamic and variable during gameplay, an optimal immersive experience occurs when ability and challenge remain balanced. Third, adaptive games should provide appropriate support to keep the player progressing optimally by continuously estimating the learner's skill level and adjusting difficulty accordingly. Meeting these adaptive design goals requires integration of individualized entry-level difficulty and dynamic in-game difficulty progression (Ben Itzhak *et al.*, 2023). When mismatches between skill and game difficulty occur, motivation, engagement, and learning outcomes can be substantially influenced.

The PhiCube system addresses these requirements through an automated difficulty adaptation engine. According to technical specifications provided by the system engineers, the platform monitors real-time performance metrics to automatically calibrate game difficulty during live sessions. By embedding these adaptive capabilities into the system's backend, the platform ensures that the training balances patient progression with task completion, while retaining the therapist's ability to make parameter adjustments as needed for individual patient needs.

2.2.4 Critical Design Parameters for Rehabilitation Games

Moulaei *et al.* (2023), with the background from Medical Informatics Research Center in Kerman University of Medical Sciences, conducted a comprehensive scoping review analyzing essential parameters for designing effective upper limb rehabilitation games. Among 99 identified parameters across ten categories, four emerged as most critical: (1) increasing patients' motivation to perform rehabilitation exercises, (2) adjustable game difficulty levels, (3) game enjoyment and aesthetic attractiveness, and (4) provision of positive or negative audiovisual feedback. The review has identified improvement in musculoskeletal performance, increased user enjoyment and motivation as the most important positive outcomes, while noting mild discomfort such as nausea and dizziness as potential negative effects.

Kiili *et al.* (2012) further emphasized that educational games must carefully balance cognitive load, as excessive information processing demands can impair learning despite high engagement levels. For children with motor impairments, this balance becomes more critical, as physical effort must be considered alongside cognitive demands to prevent overwhelming or frustrating experiences that lead to disengagement.

2.2.5 Design Strategies for Sustaining Patient Engagement

Self-monitoring capabilities can empower patients to track their own progress through activity monitors and visual feedback systems. Studies have demonstrated that self-monitoring interventions can positively influence adherence when patients receive visual feedback on their physical activity (Argent, Daly and Caulfield, 2018). However, it is important to note that existing evidence primarily derives from general physical activity interventions rather than targeted therapeutic exercises in specific rehabilitation populations. This gap highlights the need for self-monitoring systems specifically designed to accommodate the nuanced requirements of individualized rehabilitation programs, where exercise parameters such as range of motion, joint involvement, and movement quality should be precisely tracked and adapted to each patient's unique capabilities and limitations.

Educational support through multimodal instructional materials—including written information, video demonstrations, and interactive tutorials—can help enhance patient understanding of therapeutic rationale and proper exercise execution. The combination of written and verbal instruction yields superior adherence compared to verbal instruction alone (Argent, Daly and Caulfield, 2018). By facilitating the delivery of diverse educational formats, digital health platforms can be tailored to different learning preferences and developmental levels.

Beyond technical parameters, the presence of social and motivational support remains essential for pediatric adherence. Within clinical environments, this is primarily facilitated through immediate positive reinforcement from both the therapist and accompanying family members, which serves as a critical emotional support during the exercises (Argent, Daly and Caulfield, 2018). Furthermore, gamification elements—such as real-time progress visualizations and adaptable difficulty levels—can be integrated to enhance the intrinsic appeal of the movement. By transforming repetitive therapeutic tasks into goal-oriented challenges with clear, immediate feedback, these techniques may leverage a child’s natural inclination toward play to sustain engagement throughout the clinical session.

2.3 Design Practices in Pediatric Rehabilitation

2.3.1 From Universal Principles to User-Centered Design Methods

While rehabilitation platforms are usually used by both therapists and patients, inclusive design approach may be suitable for guiding the design practice. Inclusive design is defined as a design approach that seeks to ensure products and services are usable by as many people as reasonably possible, recognizing the diversity and variability of human capabilities across the whole population. Rather than focusing on specific user groups or disabilities, inclusive design aims to minimize unintentional exclusion by addressing variations in users’ sensory, cognitive and motor abilities, as well as situational and environmental constraints, within practical design limitations (Clarkson *et al.*, 2013). This approach has roots in related frameworks, including Universal Design, which advocates designing products and environments to be usable by all people to the greatest extent possible without the need for adaptation (Goldsmith and Architects, 2000), and

Design for All, which similarly emphasizes accommodating a wide range of human abilities, ages and circumstances (Clarkson *et al.*, 2013).

These frameworks have informed the development of accessibility standards, most notably the Web Content Accessibility Guidelines (WCAG), which provide internationally recognized recommendations for making digital content perceivable, operable, understandable and robust for users with diverse abilities (W3C, 2023). WCAG establishes baseline accessibility requirements for digital systems and has been widely adopted across digital platforms.

However, accumulating empirical evidence suggests that while such universal principles offer valuable foundational guidance, they may be insufficient when applied to highly heterogeneous populations with complex and intersecting needs. Friedman and VanPuymbrouck (2021) examined telehealth utilization among persons with disabilities during the COVID-19 pandemic, identifying significant disparities across disability groups. Their findings showed that despite widespread general accessibility features, deaf, blind, and/or intellectually and developmentally disabled individuals faced substantial access barriers. Critically, educational level consistently predicted telehealth non-use across groups, highlighting that technical accessibility alone cannot address low literacy and limited technology literacy barriers. The authors concluded that digital health platform accessibility features need to be greatly expanded in order to ensure equitable access, calling for explicit consideration of literacy, navigation ease, and disability-specific tools (e.g., screen readers, speech recognition, closed captioning) in design and development (Friedman and VanPuymbrouck, 2021).

Similarly, van Calis *et al.* (2025) examined the limitations of general inclusive design guidelines for digital platforms targeting individuals with mild intellectual disabilities (MID) or low literacy (LL) skills. The authors noted that while frameworks such as Universal Design and WCAG provide valuable high-level principles, they offer limited guidance on specific design elements that effectively balance accessibility and usability for populations with cognitive and literacy challenges. To address this gap, van Calis *et al.* (2025) adopted a user-sensitive inclusive research approach—a methodology originally proposed by Newell *et al.* (2011) that centers marginalized users in the design process and employs qualitative methods with modest yet diverse participant samples to deepen understanding of varied needs. Through semi-structured interviews and usability testing with MID and LL participants, the authors identified four core design elements critical to this population: (1) recognizable, well-designed visuals that reflect societal diversity; (2) clear naming conventions to improve platform findability; (3) accessible tutorial processes that scaffold initial engagement; and (4) intuitive navigation features incorporating read-aloud and read-along functionalities to support users across literacy levels.

Together, these studies underscore a critical insight: the goal of achieving inclusivity requires moving beyond compliance with generic accessibility standards toward understanding the specific needs, challenges, and preferences of target user populations through user-centered research methodologies. For pediatric rehabilitation platforms serving children with diverse motor and cognitive abilities, this principle carries particular importance.

2.3.2 Designing for Cognitive and Literacy Diversity

Children undergoing rehabilitation exhibit significant cognitive and literacy diversity, shaped by developmental stage, educational experience, and the nature of their underlying conditions. Designing gamified rehabilitation platforms that are accessible and engaging across these differences requires targeted attention to cognitive development, literacy levels, and interaction complexity.

Cognitive Development and Age-Appropriate Interface Design

Piaget's theory of cognitive development provides foundational guidance for age-appropriate interface design. Children in the preoperational stage (approximately 2–7 years) rely on concrete thinking and benefit more from visual representations than abstract symbols; those in the concrete operational stage (approximately 7–11 years) can handle moderate logical complexity but still require tangible, observable elements rather than purely abstract concepts (Piaget, 1952). To accommodate younger target users, pediatric rehabilitation platforms should prioritize concrete visual metaphors and avoid abstract concepts wherever feasible. Interface elements should employ high-contrast, unambiguous iconography that children can interpret without extensive text labels. As demonstrated by van Calis *et al.* (2025), recognizable visuals that reflect societal diversity enhance both accessibility and user identification. Furthermore, interfaces should minimize simultaneous choices and avoid nested navigation structures that exceed children’s working memory capacity. Children also benefit from immediate, concrete feedback—specifically, instant visual or auditory confirmation of actions that communicates success or error through intuitive modalities, such as color changes, animations, and sound effects, rather than abstract numerical scores or text messages.

Literacy Diversity and Multimodal Function Support

Literacy levels among children in rehabilitation vary widely, driven by age, educational interruptions due to medical treatment, and cognitive impairments associated with their conditions. Friedman and VanPuymbrouck (2021) identified literacy as a critical barrier to digital health access, finding that low literacy significantly predicted telehealth non-use even when basic accessibility features were implemented. This finding underscores that technical accessibility does not automatically ensure usability for users with literacy challenges.

van Calis *et al.* (2025) outlined several design strategies for users with low literacy. First, text content should be accompanied with optional, on-demand audio narration, with synchronized visual highlighting to support emergent literacy skills through read-aloud and read-along functionalities. Second, navigation elements and game titles should use simple, high-frequency vocabulary familiar to young children. Third, initial tutorials should prioritize visual demonstration and audio instruction over text-heavy explanations, with step-by-step scaffolding that introduces interface elements incrementally to create accessible learning experiences. Finally, information should be presented in small, digestible units with clear visual separation, avoiding dense text paragraphs that may overwhelm children with limited reading fluency.

Design Implications for Cognitive and Literacy Adaptation

Synthesizing these insights, the PhiCube platform may prioritize concrete visual interfaces that rely on intuitive iconography, color coding, and animation over text labels and abstract symbols. Text should function as supplementary rather than primary information, to accommodate young children's cognitive characteristics. Important text content needs to be paired with optional audio narration and visual demonstrations, ensuring multimodal accessibility for pre-readers and patients with reading difficulties. Games need to launch with minimal rules and interface elements or introduce additional features incrementally as children demonstrate mastery. This progressive complexity helps to prevent cognitive overload. Language for pediatric users may employ vocabulary appropriate to the youngest target group, with short and syntactically simple sentences. Finally, navigation complexity needs to be minimized by reducing menu depth and the number of simultaneous choices, to avoid exceeding users working memory capacity.

2.3.3 Designing for Motor Ability Diversity

Children undergoing neuromotor rehabilitation exhibit diverse motor abilities, which can be categorized using standardized systems such as the Gross Motor Function Classification System (GMFCS) and Manual Abilities Classification System (MACS) that range from Level I (independence) to Level V (complete assistance required) (Trabacca *et al.*, 2016). Accommodating this diversity requires adaptive systems tailored to individual motor capabilities across recovery phases. Similarly, this requirement needs to be applied to the accompanying rehabilitation games used in gamified rehabilitation platforms.

Phased Adaptive Training Framework

Mancisidor *et al.* (2019) proposed an inclusive control framework for neuromotor rehabilitation systems that addresses the continuum of patient recovery through three training modality categories. For acute recovery phases characterized by limited voluntary movement, "Assistive

Modes" encompass a spectrum from passive control, where the system executes entire movements without user input, to assistive control, where the system provides support proportional to movement error, to active control, where users perform movements independently with minimal support. Critically, these modes can be combined adaptively, with progression scaled from passive to assistive to active—maximizing patient agency while ensuring task completion. This design principle is highly relevant for pediatric populations, as children benefit significantly from experiences that balance autonomy with task completion.

For intermediate recovery phases, when patients have regained the ability to initiate voluntary movement but demonstrate poor coordination, "Corrective Modes" employ progressive force correction proportional to trajectory deviation. When movement exceeds safe boundaries, the system increases assistance to guide the limb back to acceptable ranges, providing continuous error feedback that supports motor learning while maintaining safety. Compared to traditional threshold-based methods, this progressive correction approach—delivering graded feedback that increases with deviation magnitude—better facilitates motor skill acquisition through sustained, context-aware error signaling.

For late-stage rehabilitation when patients possess adequate movement control but require strengthening and refinement of motor skills, "Opposition Modes" include resistive control (applying forces opposing movement direction), error amplification (magnifying trajectory deviations to enhance error awareness and motor adaptation), and random disturbances (training reactive motor responses to unexpected perturbations). These opposition strategies serve to address the need for progressive challenge escalation to drive continued motor function improvement in later rehabilitation phases.

Design Implications for Adaptive Motor Training

The Mancisidor *et al.* (2019) framework offers many actionable design implications for gamified pediatric rehabilitation platforms. Games need to incorporate not only adjustable entry difficulty levels, but also multi-level adaptive difficulty systems with dynamic in-game adaptation that escalates or reduces challenge based on real-time performance monitoring. Rather than binary "help/no help" options, games may need to implement progressive assistance that increases incrementally when patients struggle, preserving their sense of agency while preventing failure and frustration. Visual or auditory cues can help signal assistance level changes to maintain user context awareness.

For pediatric patients in late rehabilitation phases, games may offer optional challenge modes that introduce controlled resistance to maintain engagement and promote continued skill development. These modes need to be clearly optional and reward-based rather than mandatory to avoid discouragement. The platform should enable therapists to configure individualized movement range constraints, maximum force thresholds, and assistance parameters based on each patient's capabilities and therapeutic goals, with the system automatically enforcing these safety boundaries during gameplay. Critically, difficulty transitions and adaptive assist mechanisms need to be adjusted gradually rather than abruptly, preserving the patient's sense of control and preventing frustration or anxiety stemming from unexpected system behavior changes.

In the context of the PhiCube platform, these requirements are operationalized within the device adjustment function, categorizing system behavior into two primary modes. The first is the "Assistive Mode", which corresponds to the framework's requirement for progressive assistance. This mode provides mechanical support to help the patient complete the range of motion (ROM) when struggling, thereby preserving a sense of accomplishment while preventing failure. The second is the "Resistive Mode", which corresponds to the optional challenge modes for patients in later rehabilitation phases. This introduces controlled mechanical resistance to promote muscle strengthening and continued skill development.

Consistent with the need for clinical control, these parameters are strategically positioned within the pre-game configuration interface of PhiCube platform. This enables the therapist to establish individualized device settings before the session begins. Furthermore, to address real-time clinical needs without disrupting patient engagement, these settings are proposed to remain accessible through an in-game setting menu, structured within a parameter hierarchy that differentiates between gameplay difficulty metrics and device adjustment, allowing for quick, on-demand adjustments based on the patient's real-time performance.

2.4 Summary and Outline

This chapter synthesizes theoretical frameworks and empirical research across critical domains to inform the design of inclusive, gamified pediatric rehabilitation platforms. Section 2.1 identified adherence and motivation as key challenges influential to rehabilitation outcomes. Section 2.2 examined the role of gamification in enhancing adherence and engagement in pediatric rehabilitation contexts. The evidence demonstrates that gamification strategies can help increase children's motivation to engage with repetitive therapeutic exercises (Hamari *et al.*, 2016; Kiili *et al.*, 2012). However, existing gamified rehabilitation systems often lack sufficient adaptivity to accommodate the diverse needs of pediatric populations, revealing a critical gap between general gamification principles and the specific requirements of individual patients.

Section 2.3 focused on this gap by exploring relevant inclusive design principles. It emphasized that while universal accessibility standards provide foundational guidance, achieving genuine inclusivity requires moving beyond generic compliance toward user-centered understanding of target population needs (Friedman and VanPuymbrouck, 2021; van Calis *et al.*, 2025). For pediatric rehabilitation platforms, this reveals two critical design considerations. First, cognitive and literacy diversity necessitates concrete visual interfaces, multimodal instruction and feedback, progressive complexity introduction, simplified language, and reduced navigation complexity. Second, motor ability diversity requires adaptive training systems that accommodate the continuum across recovery stages, with progressive assistance mechanisms preserving patient's agency while ensuring task completion (Mancisidor *et al.*, 2019).

These insights provide a theoretical foundation for designing gamified rehabilitation platforms that balance engagement and adaptation. The design implications identified in this chapter inform the subsequent empirical research and design practices, deriving design strategies for the PhiCube platform.

Chapter 3. User Research

This chapter identifies the user needs and design opportunities for the PhiCube platform by synthesizing empirical data with clinical perspectives. The analysis is structured into two primary components: first, an examination of qualitative stakeholder interviews provided by Rehabilia Technologies to capture real-world clinical challenges; and second, a targeted analysis of pediatric patient profiles, focusing on the motor and cognitive characteristics of Neurodevelopmental Disorders (NDDs). By integrating these perspectives, the chapter examines the challenges of sustaining engagement, the necessity of cognitive alignment in gamified tasks, and the importance of maintaining therapeutic integrity. It also incorporates an initial consideration of clinical constraints to ensure that the design interventions are contextualized within the practical rehabilitation workflows.

3.1 User Interview Analysis

The analysis of the company's existing user research materials provides insight into the discrepancies between current gamification design for rehabilitation and cognitive expectations of pediatric neuromotor rehabilitation. The materials capture the perspectives of a range of clinical and technical stakeholders involved in rehabilitation delivery and clinical technology adoption, including neuropsychiatrists, rehabilitation therapists, bioengineers, and pediatric rehabilitation center managers, alongside the perspectives of parents of pediatric rehabilitation users.

3.1.1 Research Materials and Participant Context

This analysis is based on a synthesis of 14 anonymized interview records provided by Rehabilia Technologies. These materials consist of structured summaries rather than raw transcripts. Participants represented diverse roles across the pediatric neuromotor rehabilitation context, with clinical and technical stakeholders forming the primary participant group, and parents of pediatric users contributing perspectives on rehabilitation technology use. All participants were anonymized in the source materials, with records structured to capture stakeholder insights, challenges, and perceived needs in pediatric rehabilitation—with a specific focus on identifying improvement opportunities for gamified platforms in clinical settings.

3.1.2 Analytical Approach

The analysis followed a thematic coding approach informed by Braun and Clarke (2006), adapted to the nature of the source materials, which consisted of pre-processed summaries rather than raw transcripts. After repeated reading of all 14 records to gain familiarity with the data, initial open coding was used to label key concepts regarding pediatric engagement, cognitive load, interface design, and therapeutic requirements. Similar insights were then grouped into focused categories by synthesising the shared concerns across different stakeholder groups. Through interpretive review, these categories were refined into broader themes to identify the main misalignments between current gamified rehabilitation design and the cognitive and motor needs of pediatric patients. This iterative process aimed to remain grounded in the original data and to derive the final themes that could provide clear design insights for the PhiCube platform.

3.1.3 Thematic Analysis

The thematic coding of the company's records identified three interrelated themes that reveal the current challenges and user needs in gamified pediatric rehabilitation. These themes reflect a consensus among clinical and technical stakeholders that current technology often fails to align with pediatric engagement expectations, cognitive profiles, and the therapeutic requirements of motor recovery.

Theme 1: The Gap Between Gamified Tasks and Children's Gaming Expectations

The records consistently identify patient engagement as a critical factor of successful motor recovery. Clinical stakeholders, particularly therapists and neuropsychiatrists, noted that the repetitive exercises are inherently difficult for children to sustain. A primary challenge identified is the significant disparity between the games offered by clinical devices and the high-quality experiences available in the mainstream gaming market. Therapists observed that when gamified tasks lack sufficient variety or age-appropriate adaptation, pediatric patients would disengage. This lack of engagement is viewed not merely as a loss of motivation, but as a foundational barrier to participation; without sustained interest, children are unable to complete the volume of motor repetitions necessary for functional improvement.

Theme 2: Cognitive Overload and the Limitations of Adult-oriented Interfaces

The analysis revealed a recurring issue where gamified tools used in pediatric care are usually adapted from adult or geriatric systems. Center managers and therapists noted that these generic interfaces often overlook the unique cognitive, attentional, and linguistic comorbidities—such as those associated with Cerebral Palsy or Autism—that often accompany motor impairments. This misalignment can create an excessive cognitive load, where children struggle to understand task mechanics, shifting their focus away from the intended therapeutic movements. Consequently, clinicians emphasized that individualized personalization of task complexity is essential to ensure that the technology remains accessible to children with diverse neurodevelopmental and motor profiles.

Theme 3: The Integration of Gamification with Therapeutic Purpose

While stakeholders recognize the value of gamification for boosting motivation, they expressed a critical need to ensure that interactive elements remain subservient to clinical outcomes. A central concern identified by both therapists and center managers is the potential misalignment between gameplay success and therapeutic integrity, where a child might prioritize game objectives over the correct execution of motor patterns**.** Rehabilitation therapists cautioned that if game mechanics are not strictly aligned with therapeutic movement goals, children may adopt compensatory movement patterns to achieve in-game rewards. Given that pediatric rehabilitation requires targeted training to maintain or enhance functional abilities, therapists emphasized that the software should ensure that interactive elements reinforce the specific motor and cognitive goals defined by the clinician.

3.1.4 Clinical and Operational Constraints

The feasibility of rehabilitation platforms is often influenced by operational constraints inherent to the professional rehabilitation environment. A primary consideration is the requirement for data privacy and informed consent, particularly as the primary users are minors. From a design perspective, this necessitates secure authentication for clinical staff and transparent interfaces that facilitate parental consent, ensuring that data collection for clinical documentation and monitoring needs aligns with ethical protocols. Furthermore, game mechanics must be designed to ensure therapeutic safety and prevent non-clinical movement patterns. Acknowledging these factors helps ensure the design remains compatible with the ethical and professional standards of a pediatric clinical setting.

3.1.5 Synthesis of Key Insights

The thematic analysis indicates that engagement challenges in pediatric rehabilitation often arise from a fundamental mismatch between gamification design and the specific developmental profiles of pediatric users. The findings suggest that sustaining interest and ensuring therapeutic progress may depend on how well the gamified tasks account for age-appropriate expectations, individual cognitive and motor differences, and therapeutic objectives. In this clinical context, gamification functions less as an external motivational layer and more as a structural design element that, when appropriately aligned, can reinforce the motor patterns targeted during therapy.

These user-centered requirements are further contextualized by the operational realities of pediatric clinical practice. Integrating innovative technology into this environment requires a balance between design functionality and practical constraints, such as data privacy, clinical documentation standards, and regulatory considerations. Collectively, these insights and constraints may highlight the need for a system that recognizes the importance of cognitive accessibility and therapist-led guidance, to better support the motor recovery process within the clinical workflow.

3.2 Pediatric Patient Cognitive-Motor Profiles

Based on the clinical and stakeholder insights from Section 3.1, this section contextualizes the challenges identified in the stakeholder interviews by examining the functional profiles of the primary patient group targeted by the PhiCube platform. In pediatric neuromotor rehabilitation, children with Neurodevelopmental Disorders (NDDs)—specifically Cerebral Palsy (CP) and Developmental Coordination Disorder (DCD)—present multidimensional needs that span motor, cognitive, and sensory domains.

These conditions are rarely isolated motor impairments. As highlighted in the preceding Thematic Analysis (Theme 2), the co-occurrence of cognitive and attentional challenges significantly impacts how these users interact with gamified interfaces. For instance, while a child with CP may require support for spasticity management and bilateral coordination, they may simultaneously struggle with motor planning and sustained attention (Mahale *et al.,* 2022). In contrast, rehabilitation for DCD often focuses on movement precision and execution through structured training (Ribas *et al.,* 2023). The cognitive factors are critical in a gamified setting, as overly complex mechanics or abstract feedback can lead to cognitive overload, shifting the child's focus away from the intended therapeutic movement.

Consequently, the patient user is not a monolithic category but exists along a capability continuum. Designing for this group requires a move beyond generic interfaces toward adaptive accessibility, ensuring that task complexity can be personalized to match the specific motor and cognitive profile of each pediatric patient.

Within this context, device-assisted systems like PhiCube offer opportunities to address the limitations of traditional, monotonous therapy by integrating structured repetition with motivating virtual environments (Ashkenazi *et al.,* 2013). However, the effectiveness of such systems may require adequate cognitive accessibility. In this study, this is conceptualized not only as an accommodation for children with diverse abilities but also as a form of usability enhancement intended to improve the gamified rehabilitation training experience for a wider range of users.

Chapter 4. Case Study

4.1 PhiCube

4.1.1 Analysis of Design Functions

The design rationale of PhiCube aligns with theoretical principles in neurorehabilitation. Rehabilitative training enhances the brain's capacity to reorganize neural pathways through repetitive practice, thereby establishing a neural foundation for motor recovery. High-intensity, task-oriented training through repeated practice facilitates motor learning and contributes to improved motor control. The integration of gamified elements responds to the recognized challenge in pediatric rehabilitation, which revolves around the monotony of repetitive training and low adherence, by situating therapeutic movements within engaging, scenario-based activities intended to enhance motivation and training continuity.

The adaptive motor learning context provided by PhiCube is one of its important functions. It enables dynamic adjustment such as assistance mode and resistance mode according to the patient's real-time performance. These design aim to maintain the patient in a training state that is challenging yet not discouraging. PhiCube focuses on assisting upper-limb motor training at the hardware level. The accompanying software extends this focus by embedding therapeutic movements within task environments that also consider cognitive dimensions, including sustained attention, response speed, and visuospatial perception training. In doing so, it reflects principles found in neurodevelopmental approaches to pediatric rehabilitation (Physio-pedia, n.d.).

From a design perspective, the functional features of PhiCube correspond to the multidimensional rehabilitation needs of children with neurodevelopmental disorders. Its upper-limb training modules, gamified repetition mechanisms, performance monitoring, and adjustment capacities align with key principles: repeated practice supports functional recovery and motivation helps enhance treatment adherence. Specifically, adaptive resistance training may contribute to progressive muscle strengthening; guided movement correction may support more precise motor trajectories; and bilateral synchronous training modules may enhance upper-limb coordination for patients with relevant motor impairment. Furthermore, progressively graded game-based tasks and real-time feedback mechanisms may support increasing motor planning complexity, improving movement precision, and extending sustained attention, which are consistent with the rehabilitation goals relevant in DCD. The integration of gamified elements may also enhance motivation and engagement, contributing to sustained participation in rehabilitation activities.

4.1.2 Analysis of Software Design Values

The design values pursued by the supporting software of PhiCube in the scenario of clinical pediatric upper limb rehabilitation mainly include three categories. Its design is carried out around the needs of pediatric patients, clinical therapists, and rehabilitation treatment processes. The design of various functions is oriented to adapting to the rehabilitation characteristics of pediatric patients with neurodevelopmental conditions involving upper-limb motor impairment, to assist them in performing motor bilateral therapies.

The values of the PhiCube software for child patients include reducing the cognitive demands of rehabilitation training comprehension, helping them understand training tasks, and facilitating their training participation. It should be clearly stated that this software is not intended for the clinical treatment of cognitive disorders, but to build a cognitively accessible environment for upper limb motor rehabilitation, specifically responding to the core needs of child patients during training: helping them understand the requirements of training behaviors by setting clear task objectives and establishing links between actions and feedback; maintaining children's training attention and participation motivation through a gamified training structure combined with real-time feedback and incentive elements; avoiding excessive cognitive load on children by designing predictable interactive logic and adapting progressive training difficulty. The software is also designed with forms such as visual-motor tests (e.g., target tracking tasks) and visual-perceptual tasks (e.g., go/no-go, classification, memory tasks). To prevent patient disengagement, it features multiple mini-game variants for the same therapeutic skills and difficulty progressions. By embedding motor training tasks into a clear, goal-oriented process, it provides support for improving the cognitive accessibility of rehabilitation training and children's participation.

For clinical therapists, the values of the PhiCube software include providing interpretable clinical data and treatment decision support. The design logic of the software includes converting the limb movement behaviors of child patients into quantifiable clinical evaluation indicators, such as joint range of motion, normalized jerk value reflecting motor fluency, bilateral limb movement asymmetry, reaction time, error rate, and visual-motor coordination. These indicators are intended to be supportive for therapists to interpret, and the converted clinical indicators aim to help provide objective data support for rehabilitation evaluation. At the same time, the software is exploring the clinical process continuity between ability evaluation and gamified training in its design, so that similar tasks have dual attributes of ability testing and training. This design may thus help reduce therapists' learning cost of switching cognitive modes between the evaluation system and the training system, which may improve the continuity and efficiency of clinical operations in the use of PhiCube.

For the clinical rehabilitation treatment process, the values pursued by the PhiCube software include providing support for patient-oriented rehabilitation treatment. The software provides the possibility of practical operation for personalized treatment through a number of functional designs: it supports therapists to adjust device setting parameters according to the actual rehabilitation needs of patients, realizing the training mode of on-demand assistance; it can flexibly select training tasks, covering different dimensions such as visual-motor coordination and visual-perceptual ability training; and it can adjust training rhythm or task complexity according to patients' training performance. Through adaptive training tasks and quantifiable evaluation indicators, the software provides practical possibilities for therapists to formulate personalized rehabilitation intervention plans and monitor patients' rehabilitation progress through interpretable indicators in clinical scenarios.

It needs to be clearly defined that the functional support of the PhiCube software for the rehabilitation of child patients such as with CP or DCD has certain dimensional boundaries and does not cover all rehabilitation dimensions, and its degree of support and positioning for each dimension are different: taking upper limb motor rehabilitation as the goal is the main support dimension of the software; for cognitive areas such as comprehension and attention ability, it mainly provides support through contextualized and gamified rehabilitation training tasks; for visual areas such as reaction and spatial perception ability on the screen, it provides support to some extents through visual-motor and visual-perceptual tasks; its support for sensory integration ability is relatively limited, providing some assistance by establishing a coupling relationship between movement with visual and audio feedback; and the rehabilitation value of supporting advanced cognitive training is not within the current design scope of the software.

4.1.3 Identification of Improvement Opportunities

To support the achievement of the values pursued by the PhiCube software, this study identified several improvement areas targeting clinical application needs, focusing on reducing the system learning cost for clinical therapists and the cognitive load on child patients users. Specifically, it aims to improve the platform information architecture, task classification and parameter clarification of the therapist operation interface to form a clearer structure that may facilitate the therapists in making clinical decisions. The specific improvement entry points are identified as follows.

At present the training mini-games provided by the PhiCube software would need to clearly convey the corresponding core therapeutic goals to the therapists, which has identified as the primary improvement entry point. Most existing mini-games have been designed to take into account upper limb motor training, cognitive ability training, and the integration of visual and attention requirements, enabling the potential achievement of multi-dimensional training effects simultaneously. However, the core training goal of the games has not yet been clearly declared, nor has the applicable patient group and rehabilitation stage for each game been suggested and explained. This may bring some difficulties for therapists to quickly understand the application purpose of specific tasks in clinical selection, and to judge its matching appropriateness with the patient's rehabilitation needs. Such difficulties may affect the efficiency of clinical decision-making (Vacca et al., 2023).

Moreover, the software provides a wealth of adjustable parameters, yet the hierarchical clinical significance of each parameter has not been clearly stated, which may increase the difficulty of operation and decision-making for therapists. At current stage, the software includes multiple adjustable parameters such as target appearance frequency, target size, spawn side percentage, player sensibility, track dimension, time goal, score goal, distractors percentage, etc. (see Figure 4). The attributes and purposes of parameters would need to be clarified and classified to help reduce cognitive load in parameter adjustment interventions.

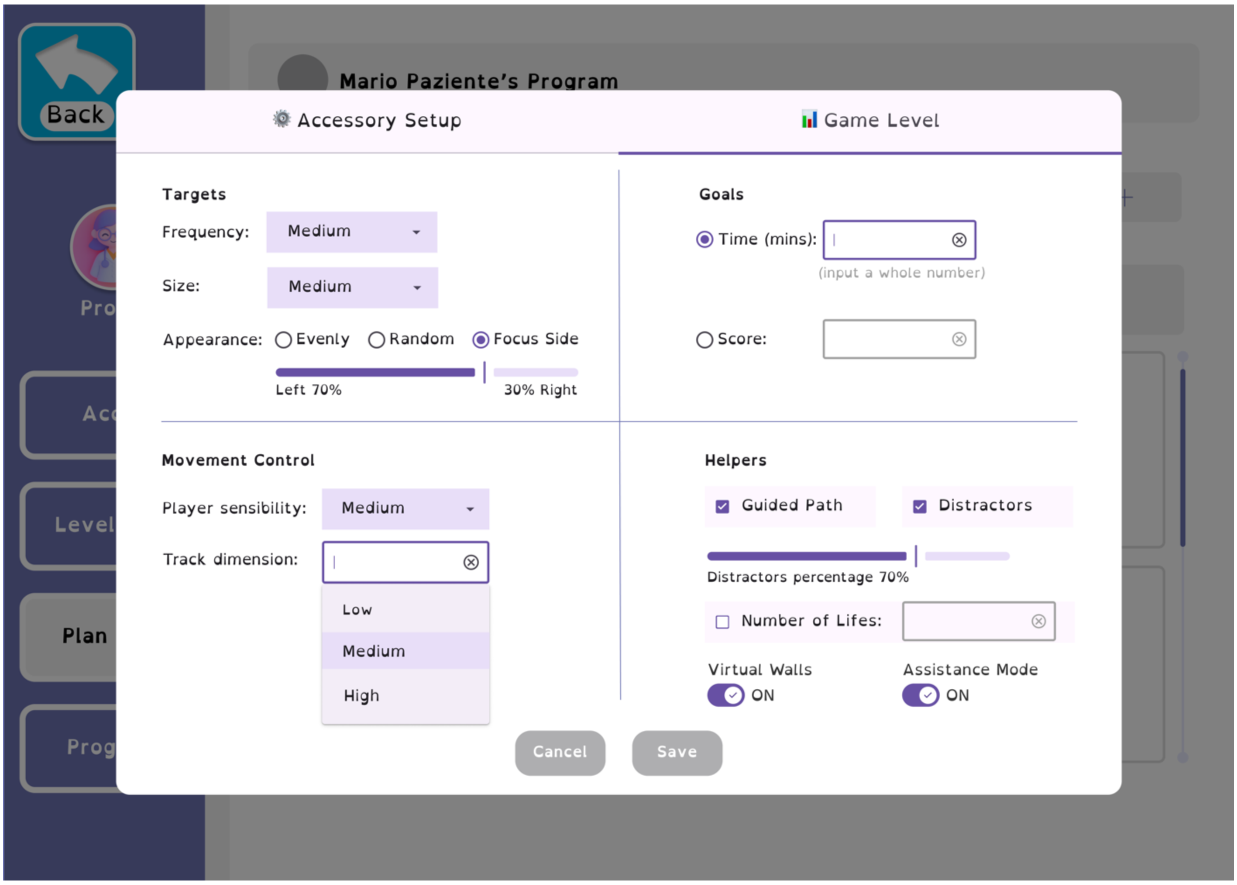

Figure 4: Initial parameter adjustment interface of PhiCube.

4.1.4 Question Formulation

Building upon the analysis of PhiCube's identified design values and areas for improvement, targeted questions and corresponding goals are proposed around these directions: enhancing the platform usability for therapists, reducing the cognitive demand for pediatric patients, and supporting therapists' clinical decision-making. The aim is to better align the platform's functions with clinical rehabilitation requirements, thereby maximizing the auxiliary value of the software in clinical settings.

To achieve this, the primary focus addresses how to minimize the learning curve for clinical therapists by streamlining the platform's functional logic and operational workflows, ensuring that the system is intuitive and easy to master. The study also explores how the PhiCube platform can further mitigate the cognitive burden on children, facilitating a gradual understanding of multi-dimensional training tasks through clearer guidance. Furthermore, the study investigates the platform's potential to assist therapists in formulating efficient rehabilitation plans—for instance, by incorporating task recommendations based on individual patient profiles and specific therapeutic goals.

In response to these questions, three main goals are proposed. The first is to enhance the cognitive accessibility of the platform for therapists through exploring a structured information architecture facilitates systemic clarity. The second goal focuses on reducing the cognitive demand during pediatric rehabilitation by embedding motor-game tasks into a visually guided, goal-oriented training process, which is intended to improve children's comprehension and adaptation to the exercises. Finally, the goal is to iteratively align the system with clinical workflows, a process that necessitates validation to gather feedback from professional practitioners in the future. This integrated approach may help ensure that the design interventions are both theoretically grounded and clinically relevant.

4.2 Benchmarking

The benchmarking process focused on systems that share its functional and technical characteristics. The selection criteria included: (1) therapeutic focus on upper-limb motor recovery; (2) the integration of physical hardware with a digital gamified interface; and (3) observed clinical prevalence within rehabilitation environments. Based on these criteria, systems such as ArmMotus™ M2 and CycleMotus™ were selected as they may represent the current standard of care in technology-assisted rehabilitation.

4.2.1 Analysis of ArmMotus™ M2 Upper Limb Rehabilitation Robot

The ArmMotus™ M2 platform interface design is characterized by a structured, multi-modal training menu that explicitly categorizes therapeutic content. The categorization includes passive movement, assisted movement, active movement, resistance training, sensory training, ROM (Range of Motion) training, movement control training, muscle strength training, attention training, isometric training, daily life activity training, and additional functional training modules, according to Fourier Intelligence (2026). This design choice reflects a deliberate effort to align the platform with clinical practice by:

- **Mapping training tasks to therapeutic goals**: As illustrated in Figure 5, the ArmMotus™ M2 employs a stratified classification where each icon explicitly maps to a distinct clinical objective, thereby reducing the therapist's cognitive load during task selection.
- **Supporting cognitive accessibility for clinicians**: The clear categorization reduces the cognitive load of navigating between different training types, enabling therapists to focus on clinical decision-making rather than system navigation.

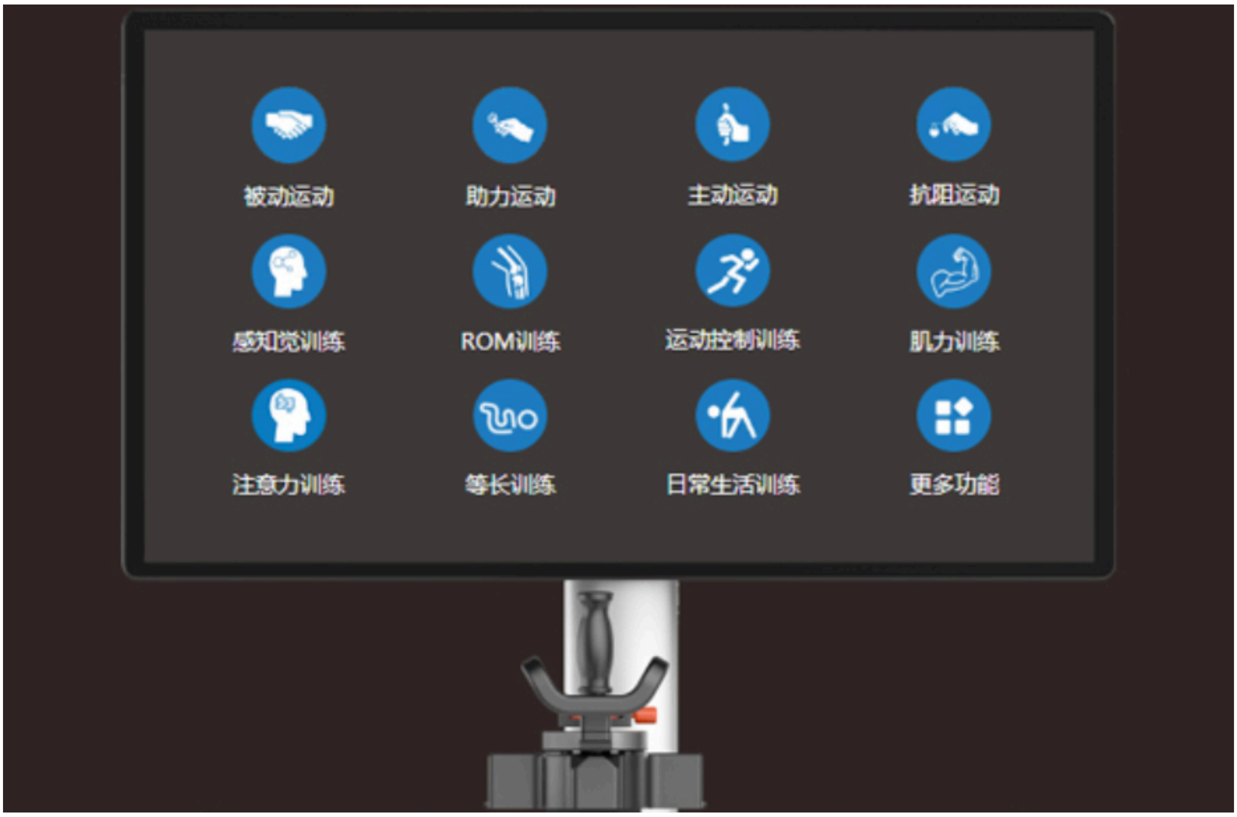

Figure 5: Goal-oriented task classification in ArmMotus™ M2 (Fourier Intelligence, 2026).

Analysis of the ArmMotus™ M2 platform also include its integration of motor and cognitive training, as its interface combines motor control training with cognitive tasks to reflect a holistic approach to neurodevelopmental rehabilitation, and the visualization of progress, as the platform generates charted test reports such as range of motion that provide objective data for clinical decision-making.

Notably, PhiCube's design aligns with these established industry practices, as its gamified training platform also integrates motor control training with cognitive tasks, and generates objective, clinical performance metrics, such as real-time position tracking and data analysis (see Figure 6), to support evidence-based clinical decision-making, demonstrating that PhiCube's core design principles are grounded in validated approaches to neurodevelopmental rehabilitation.

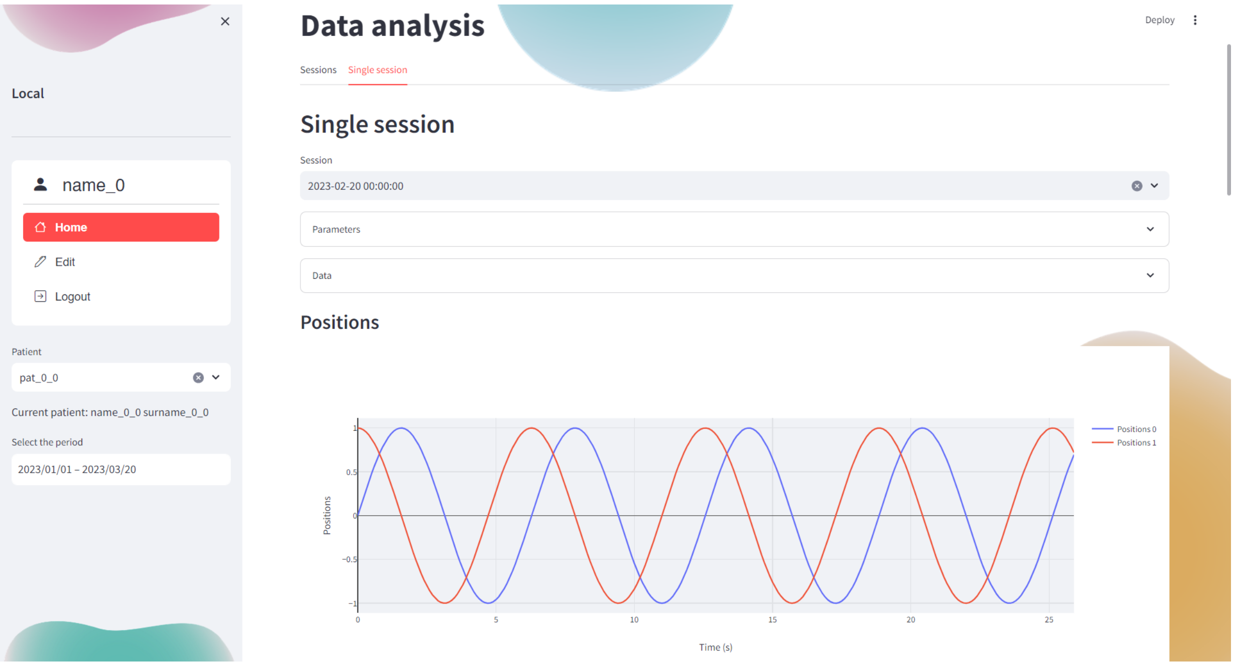

Figure 6: PhiCube data analysis and position tracking (Rehabilia Technologies, 2026).

4.2.2 Analysis of CycleMotus™ Series: Active-Passive Training System

The analysis of the product interface presented by Fourier Intelligence (2026) suggests that the platform prioritizes real-time accessibility and clinical utility, with design features that minimize disruption during active training sessions. Key observations include:

- **Quick-access toolbar for real-time parameter adjustments**: The platform includes a persistent toolbar that allows therapists to adjust resistance, speed, and other parameters without leaving the training view (see figure 7). This design minimizes navigation steps during child-facing time, ensuring that training sessions remain uninterrupted and engaging.

- **Stratification of training modes by muscle strength levels**: The platform categorizes training modes (passive, active-assisted, active) based on the patient's muscle strength grade (0–5), ensuring that tasks are appropriately matched to the patient's current abilities. This design reflects a patient-centered approach that prioritizes safety and efficacy.

Figure 7: Quick-access toolbar in CycleMotus™ (Fourier Intelligence, 2026).

To synthesize the comparative findings from the analyzed platforms, a systematic comparison grid is presented in Table 1. This matrix cross-references key design dimensions—such as task classification, operational workflow, and decision support—to highlight industry standards and identify specific improvement areas for the PhiCube platform.

Design Dimension	ArmMotus™ M2	CycleMotus™	PhiCube (Current)	Clinical Rationale
Task Classification	Explicit mapping by clinical goals (see Fig 2)	Stratified by muscle strength grades (0–5)	Integrated multi-dimensional functional training	Ensures tasks match physical and cognitive capabilities
Operational Workflow	Structured, multi-modal training menu	Persistent quick-access toolbar for real-time control (see Fig 4)	Menu-based parameter adjustment	Minimizes navigation steps
Cognitive Accessibility	Visual icons for distinct clinical objectives	Visibility of patient status and key metrics	Detailed parameter list (see Fig 1)	Reduces therapist's cognitive burden during sessions
Decision Support	Charted reports	Mode recommendations based on muscle strength grades	Objective movement tracking (see Fig 3)	Supports evidence-based planning and personalized care

Table 1: Comparative benchmarking across analyzed rehabilitation platforms.

4.2.3 Design Insights and Implications for PhiCube

The comparative benchmarking synthesized in Table 1 highlights the design opportunities for PhiCube’s gamified training platform, particularly in the areas of clinical utility and cognitive accessibility. The insights derived from this comparison are grounded in the observed strengths of competing platforms and the needs of neurodevelopmental rehabilitation.

Goal-Oriented Task Classification

The explicit categorization of training content in ArmMotus™ M2 highlights the importance of aligning gamified tasks with therapeutic goals. For PhiCube, this may suggest the need to design a structured task classification system that:

- Maps each gamified task to specific therapeutic objectives (e.g., "visual-motor coordination," "bilateral response timing").
- Clearly communicates the primary and secondary training demands of each task to therapists.
- Enables therapists to quickly select tasks that match the patient's current rehabilitation needs.

Accessibility of Settings and Status

The quick-access toolbar in CycleMotus™ underscores the value of minimizing navigation steps during active training sessions. For PhiCube, this may imply:

- Designing a context-aware interface that displays current settings and patient status (e.g., accuracy, training time) within the training view.
- Prioritizing the visibility of critical data (e.g., task progress, focus side) to support informed decision-making during sessions.

Patient-Centered Stratification of Training Modes

The training modes in CycleMotus™, stratified by muscle strength, demonstrate the importance of matching task difficulty to the patient's current abilities. For PhiCube, this may suggest:

- Stratifying training tasks based on the patient's motor and cognitive abilities (e.g., mild, moderate, severe impairment).
- Introducing appropriate difficulty levels based on initial assessments or ongoing performance data.

Supporting rather than Replacing Clinical Judgment

Both competing platforms are designed to support, rather than replace, clinical decision-making. This further supports the understanding that the PhiCube platform is intended to:

- Provide therapists with clinically interpretable data, rather than substitute for professional clinical reasoning.
- Maintain a clear distinction between gamified engagement and clinical outcomes, ensuring that therapeutic goals remain central to the platform's design.

4.2.4 Conclusion

The comparative benchmarking synthesized in Table 1 situates PhiCube within the broader landscape of gamified rehabilitation platforms, highlighting potential opportunities for differentiation in accessibility and user engagement. By exploring the integration of goal-oriented task classification, enhanced accessibility of critical settings, and patient-centered stratification of training modes, PhiCube is intended to position itself as a clinically rigorous yet engaging platform for pediatric neurodevelopmental rehabilitation. Through this iterative alignment with industry standards, PhiCube demonstrates the potential to balance gamified engagement with clinical utility, aiming to support both the child's motivation to participate and the therapist's ability to deliver personalized, evidence-based care.

Chapter 5. Define and Ideation

5.1 Therapist Persona

5.1.1 Profile Overview

Name: Dr. Elena

Age: 38

Role: Senior Pediatric Rehabilitation Therapist

Experience: 12 years in pediatric neuromotor rehabilitation

Specialization: Upper-limb interventions for Cerebral Palsy (CP) and Developmental Coordination Disorder (DCD)

Work Context: Rehabilitation center, 15-20 pediatric patients weekly

5.1.2 Professional Context

Elena leads a diverse caseload of children aged 4-12 with varying motor and cognitive profiles. The rehabilitation center recently acquired the PhiCube system, and she is responsible for integrating it into clinical practice. She values evidence-based interventions but faces daily realities of time constraints, variable patient responses, and the need to adapt protocols to individual children. Her patients range from those requiring muscle strength training to those needing coordination training, many with attentional or cognitive differences.

5.1.3 Goals

- Deliver measurable functional improvements in children's upper-limb abilities
- Maintain patient engagement throughout treatment periods
- Efficiently document patient progress and update clinical records
- Individualize treatment while maintaining structured, reproducible protocols

5.1.4 Pain Points

Challenge	Description
Unclear Game Goals	Games target multiple therapeutic goals simultaneously, but primary objective lacks declaration. Elena spends mental energy understanding which game suits which patient need.
Parameter Complexity	Adjustable parameter settings lack classification and prioritization. When children struggle, Elena finds it inefficient to decide which motor or cognitive parameters to adjust.
Insufficient Decision Support	Insufficient mapping between patient profiles (diagnosis, stage, ability) and appropriate games.
Session Flow Disruption	Multistep navigation and adjustment time causes child disengagement. Technical tasks compete with therapeutic presence.

Table 2: Pain points of the therapist Persona.

5.1.5 Cognitive and Usability Needs

Information Presentation:

- Hierarchical structure of platform functions
- Progressive disclosure of tutorial or guidance

Decision Support:

- Clear mapping between therapeutic goals and game selection
- Differentiation between motor-focused, cognitive-focused, or mixed adjustments

Session Management:

- Session templates for patient profiles
- Quick-access controls without deep menu navigation

- Visibility of current settings and patient status

5.1.6 Daily Workflow and PhiCube Interactions

Phase	Activities	Current Considerations
Pre-Session (10-15 min)	Review notes, select games, configure parameters	Game selection ambiguous; limited guidance for initial settings
During Session (30-45 min)	Instruct gameplay, monitor performance, adjust parameters	Real-time adjustment decisions cognitively demanding
Post-Session (10-15 min)	Document observations, review data, adjust treatment plan	Insufficient support for efficient clinical documentation

Table 3: Daily workflow and PhiCube interactions for the therapist Persona.

5.1.7 Key Quotes

"I need to know in seconds: is this too hard for motor, too complex for cognition, or is attention fading? And then I need to know what to adjust."

"The parameters are valuable. But I need time to reason about which metrics matter for which clinical interventions."

" I need to focus on my patient more than on performing technical tasks."

5.1.8 Representative Scenario: First Session with New Patient

The scenario integrates therapist and pediatric patient perspectives as follows.

Patient Persona: Leo

Clinical Profile: Male, 6 years old, diagnosed with Cerebral Palsy (Bilateral Upper Limbs, MACS Level III).

Cognitive Status: Demonstrates normal cognition function but low frustration tolerance, exhibits limited task persistence when faced with repetitive motor challenges.

Key Pain Points:

- Sensitivity to Task Failure: Rapidly disengages or shows emotional distress if physical motor limitations consistently prevent the achievement of in-game objectives.
- Susceptibility to Information Overload: Excessive visual complexity can impede task focus, leading to distraction during the session.

User Goals:

- Perceived Mastery and Competence: To experience a clear sense of progress through predictable interaction patterns and immediate system feedback.
- Reduced Cognitive Load: To interact with a visual environment that prioritizes task-essential information, allowing concentration on task goal achievement.

Without Design Support: Elena scrolls through games descriptions deciding appropriateness. She opens each to check parameters, making mental notes. Elena adjusts multiple parameters with uncertainty about which intervention targeting which type of ability trained. This fragmented workflow may disrupt the session's rhythm and increase the risk of distraction for patients like Leo.

With Design Support: Elena selects games which show primary focus and typical patient fit. Elena makes the targeted adjustment assisted by clarified and prioritized parameters. Template integration supports documentation. This streamlined process may help the therapist maintain focus on the patient's performance and emotional engagement.

5.1.9 Design Needs and Implications

Design Need	Design Implication
Clear game-purpose mapping	Indicate primary therapeutic goal of games with secondary objectives differentiated
Hierarchical parameter organization	Declare clinical adjustments targets; inform decision priority
Session templating	Enable efficient creation of session structures for new patients
Minimized navigation	Easy access to frequent functions; intuitive workflows
Hierarchical data visualization	Differentiate gameplay progression and performance data analytics

Table 4: Design needs and potential implications for clinical PhiCube usage.

5.2 Problem Statement

Clinical therapists using the current PhiCube platform may face challenges related to insufficient cognitive support when translating patient needs into efficient gamified rehabilitation sessions. The current platform design could obscure the relationship between therapeutic goals and game selection, while adjustable parameters may lack clear clinical targeting. Consequently, therapists may experience decision fatigue during session planning and training implementation, which could potentially limit the platform's therapeutic assistance value.

5.3 Vision Statement

PhiCube transforms pediatric rehabilitation into engaging play. It addresses motor, cognitive, communicative, and social-emotional development through a single integrated approach for children with neurodevelopmental challenges, performing motor bilateral therapies in an assisted way. It visions a future where technology seamlessly supports clinical expertise, making effective upper-limb rehabilitation accessible, engaging, and impactful, from clinics to homes.

5.4 Feature Prioritization Matrix

Design Priority: Begin with Must-Have features to support clinical usability, then layer Should-Have features to support clinical reasoning. Could-Have and Won't-Have features can be explored in future iterations.

5.4.1 Must-Have (Essential for clinical viability)

Priority	Feature	Reason
1	Movement safety boundaries setting (e.g., movement range constraints, maximum force thresholds)	Prevents excessive movements, adapt to individual abilities
2	Games clearly indicating primary therapeutic objective (e.g., "Bilateral Coordination")	Reduces ambiguity in game selection
3	Motor parameters suggesting appropriate rehabilitation stage	Therapists clearly know which motor parameter suits which patient recovery phase
4	Cognitive parameters organization differentiating adjustment target	Clarifies parameter adjustment goals; supports therapists decision-making

Table 5: Must-Have features in current PhiCube Feature Prioritization Matrix.

Usability guidelines could be considered for future evaluation of these prioritized functions, such as clarity of therapeutic goals, efficient access to parameter settings, and a consistent navigation structure to reduce cognitive burden for therapists. Specific measurable criteria may be refined through future usability testing with clinical therapists.

5.4.2 Should-Have (Important for clinical workflow)

Priority	Feature	Reason
1	Pre-configured game sequences with saved parameters	Reduces pre-session setup time
2	Quick-access real-time parameter controls without deep menu navigation	Prevents child disengagement during technical navigation; preserves therapeutic presence and session flow
3	Patient profile template integration (e.g., auto-populate key metrics into clinic's documentation format)	Reduces session administrative burden; improves documentation efficiency

Table 6: Should-Have features in current PhiCube Feature Prioritization Matrix.

5.4.3 Could-Have (Desirable enhancement)

Priority	Feature	Reason
1	Session replication and modification for recurring patients	Streamlines repeated visits; reduces redundant configuration work

Table 7: Could-Have feature in current PhiCube Feature Prioritization Matrix.

5.4.4 Won't-Have (Out of the scope of design practice)

Priority	Feature	Reason
1	Home program or patient/family-oriented features	The design practice focuses on the supervised clinical environments.

Table 8: Won't-Have feature in current PhiCube Feature Prioritization Matrix.

Chapter 6. Design and Iteration

6.1 Platform Features

Building on the user research insights and industry benchmarking findings identified in Chapters 3 and 4, and further guided by the therapist persona, problem statement, and feature prioritization framework established in Chapter 5, the goal is to integrate existing functions with newly proposed features in the design and iteration of the PhiCube platform. This process targets the clinical challenges defined previously, to better address clinical usability needs, cognitive accessibility for both therapists and pediatric patients, and therapeutic alignment in pediatric neuromotor rehabilitation.

6.1.1 Previous features

Previous features of the PhiCube platform, including login, registration, logout, the list of assigned patients, patient basic information, therapist notes, hardware parameter configuration, mini-game selection, game descriptions, in-game parameter configuration, multiple mini-game variants for the same therapeutic skills, description of involved skills, general settings, patient progress tracking, and performance data analytics, are retained and integrated with the newly proposed features. The aim of this integration is to refine a clearer, more streamlined clinical workflow for therapists using the PhiCube platform in clinical settings.

6.1.2 New features

In line with the Must-Have and Should-Have feature prioritization defined in Chapter 5, the newly proposed features target the key pain points of the therapist persona and the design challenges articulated in the problem statement. These features include individual patient ability profile, descriptions of device orientations and their corresponding supported handles and grips, device setup instructions, initial definition of movement safety boundaries, training goal declarations for mini-games, and guided gameplay instructions. These features are identified as important for supporting the safe, targeted, and accessible clinical application of the PhiCube system, representing the translation of preceding user research, industry benchmarking insights, and design definition into potential clinical-oriented design interventions.

6.2 Workflow Analysis

6.2.1 Methods and insights

Through card sorting and tree testing methods, six participants with cross-disciplinary experience in clinical rehabilitation practice, interaction design, and product development were involved in the analysis of the PhiCube platform's proposed features to inform the exploration of its information architecture and clinical workflow design. Physical card sorting was conducted with most participants (one clinical rehabilitation center operations specialist and three designers), who classified platform features and articulated their intuitive classification logic and clinical workflow expectations (see Figure 8). Further discussions on feature classification and structural validation were conducted with the PhiCube development team to refine the initial proposals.

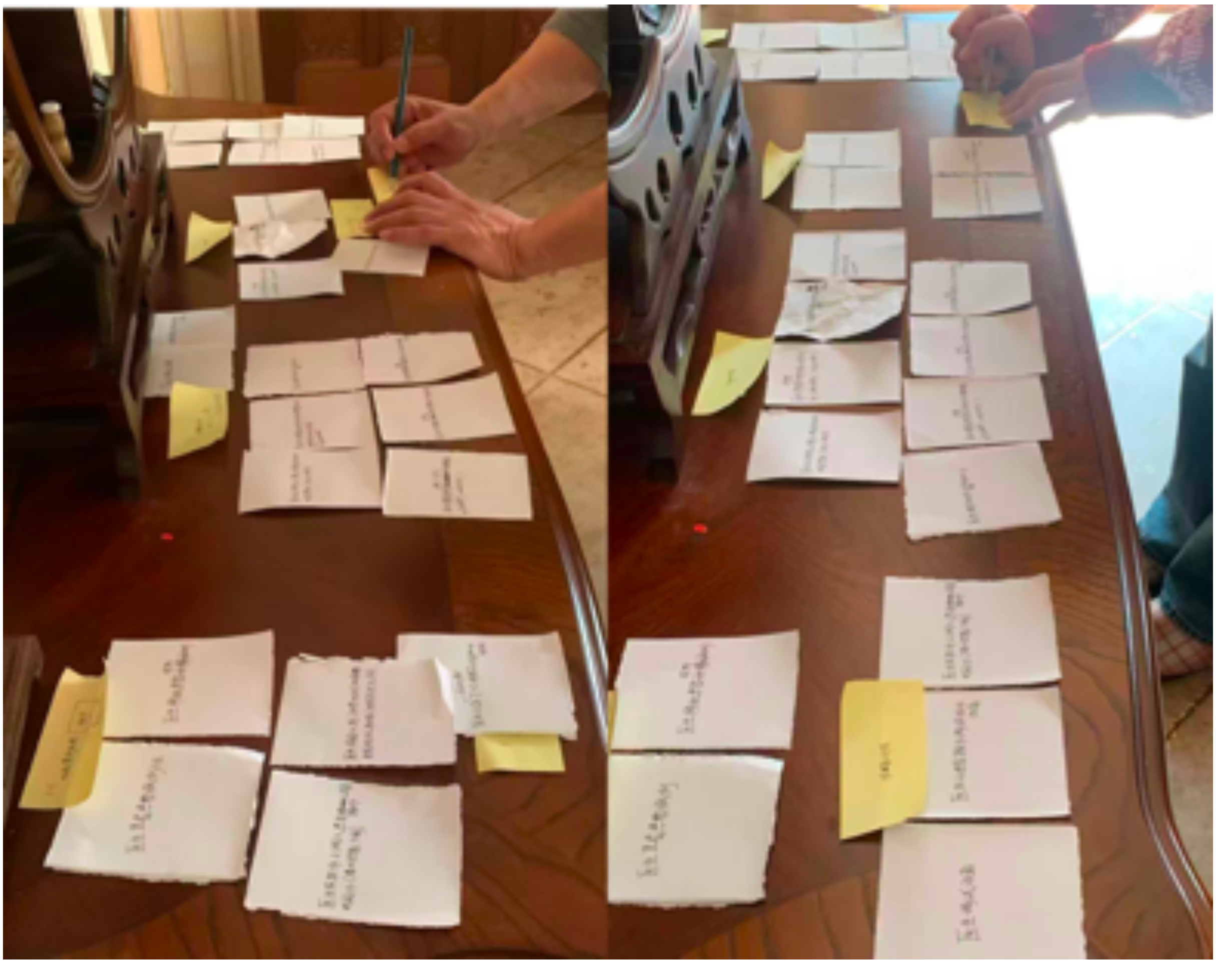

Figure 8: Card Sorting Session.

Notably, the feature of Initial definition of movement safety boundaries was highlighted as a critical addition to the proposed feature set by the clinical rehabilitation practice specialist—an expert with over 10 years of experience collaborating with pediatric clinical therapists, supporting rehabilitation interventions for children with diverse neurodevelopmental disorders, and operating a wide range of clinical rehabilitation devices. This specialist emphasized the indispensable role of this feature in pediatric rehabilitation training workflows, clarifying that configuring individualized safety boundaries (including movement range constraints and maximum force thresholds) for each pediatric patient at the initial device setup stage is critical to ensuring clinical training safety.

Moreover, insights from the clinical rehabilitation practice specialist further contextualized the typical clinical rehabilitation workflow, stressing that standardized preliminary assessments are a prerequisite for formal training initiation. These assessments typically encompass both motor function and cognitive ability evaluations: for pediatric patients, validated cognitive assessment protocols such as the Psychoeducational Profile-Third Edition (PEP-3) and the Wechsler Intelligence Scale for Children (WISC) are commonly adopted to define and adapt gamified training difficulty to individual cognitive abilities, while universal motor function assessment tools including the Gross Motor Function Classification System (GMFCS) and Manual Ability Classification System (MACS) are commonly used to evaluate pediatric patients' motor capabilities for training adaptation. Beyond these universal assessment tools, the specialist also noted that clinical rehabilitation centers often implement customized initial assessment protocols tailored to their specific patient groups and clinical practice needs.

Regarding the combined card sorting and tree testing outcomes, some disciplinary perspective differences emerged in the classification of patient profile-related features. For the individual patient ability profile, the clinical rehabilitation and interaction design participants suggested integrating both motor function and cognitive ability level descriptions to enable precise personalized training matching for pediatric patients, while the PhiCube development team highlighted a more phased, iterative design approach. This approach supports including motor function level descriptions in the platform's initial version, with cognitive ability level integration to be further refined in subsequent iterations based on real-world clinical usage feedback. This perspective difference guided the prioritization of the patient ability profile feature in the current design iteration: the initial implementation focuses on motor function characterization, in alignment with clinical workflow needs, and cognitive ability integration is marked as a potential direction for future research.

The information architecture of the therapist-oriented PhiCube platform was refined based on the integrated outcomes of card sorting and tree testing with cross-disciplinary participants, supported by practical guidance from the PhiCube development team to align with real-world platform development needs. The final information architecture for clinical workflow derived from these analyses is presented in Figures 9-13 (dark background: existing features; light background: proposed features).

This information architecture is designed to be therapist-centric, with functions structured to support clinical decision-making and workflow efficiency, focusing on the platform's functional navigation for therapists. The loop for in-session parameter adjustment is marked in Figure 12, illustrating the cycle of real-time performance monitoring, clinical judgment, and adaptive parameter configuration during gamified training. Beyond this in-session adjustment loop, the platform is also proposed to support periodic reassessment through the Patient Profile module, where therapists can review motor evaluation results and update the individual patient ability profile, which aligns with common clinical practices of ongoing evaluation and adaptation.

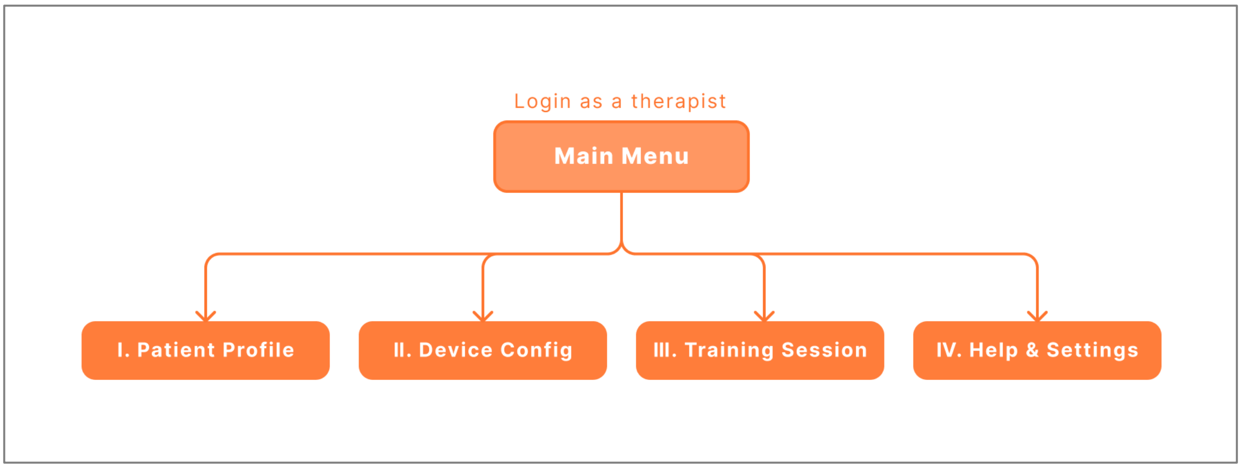

Figure 9: Proposed Therapist-Oriented IA of PhiCube – Main Menu.

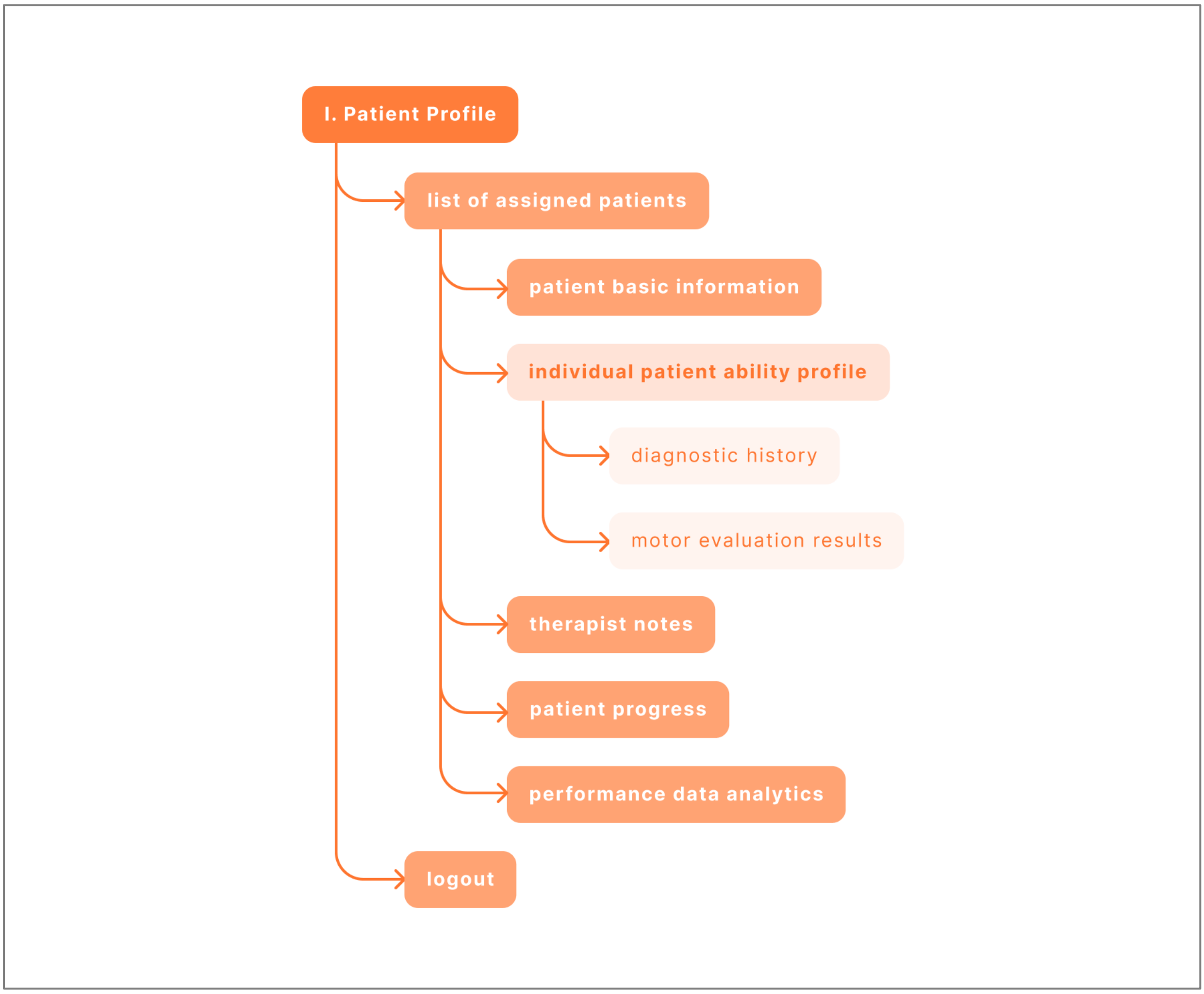

Figure 10: Proposed Therapist-Oriented IA of PhiCube – Patient Profile.

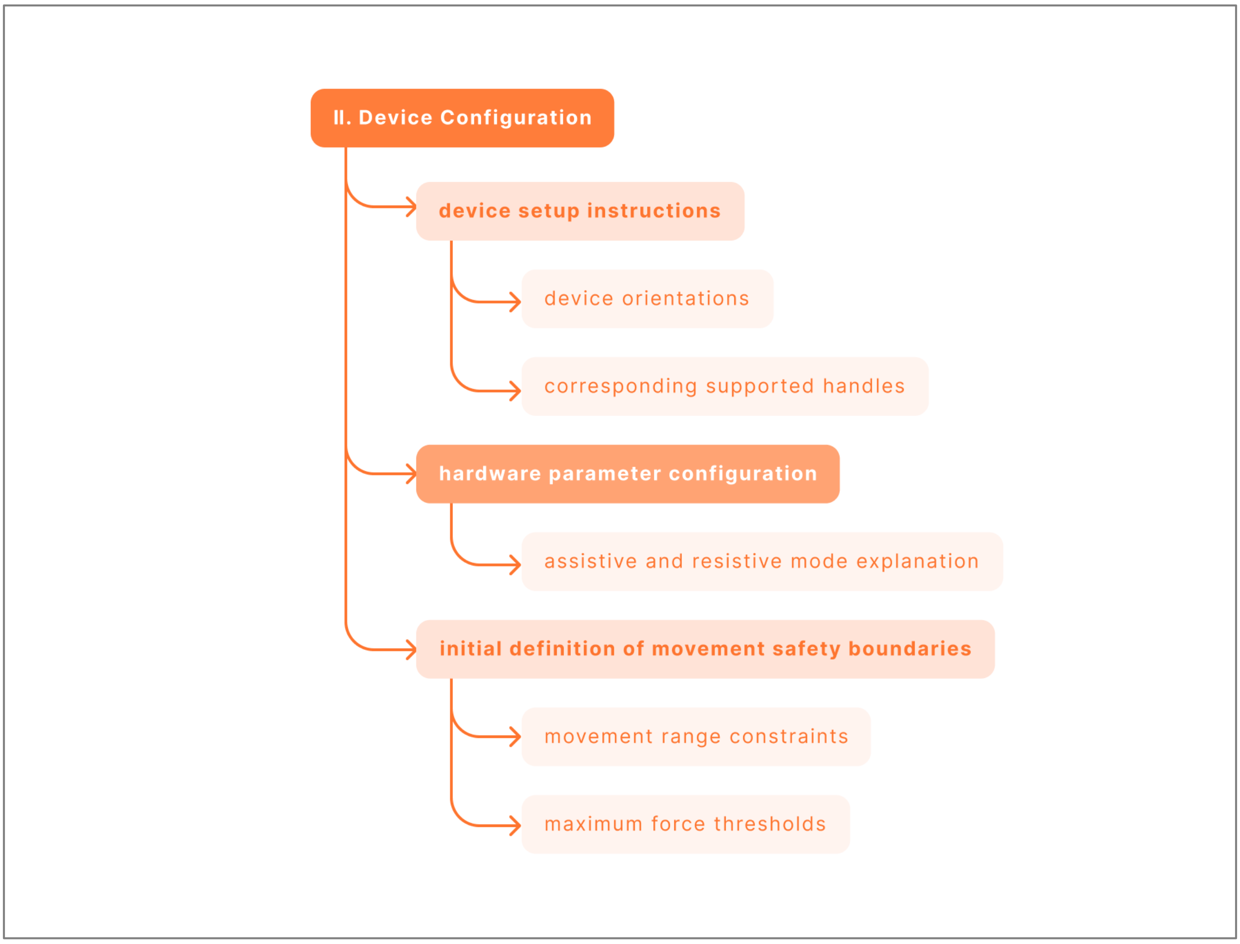

Figure 11: Proposed Therapist-Oriented IA of PhiCube – Device Configuration.

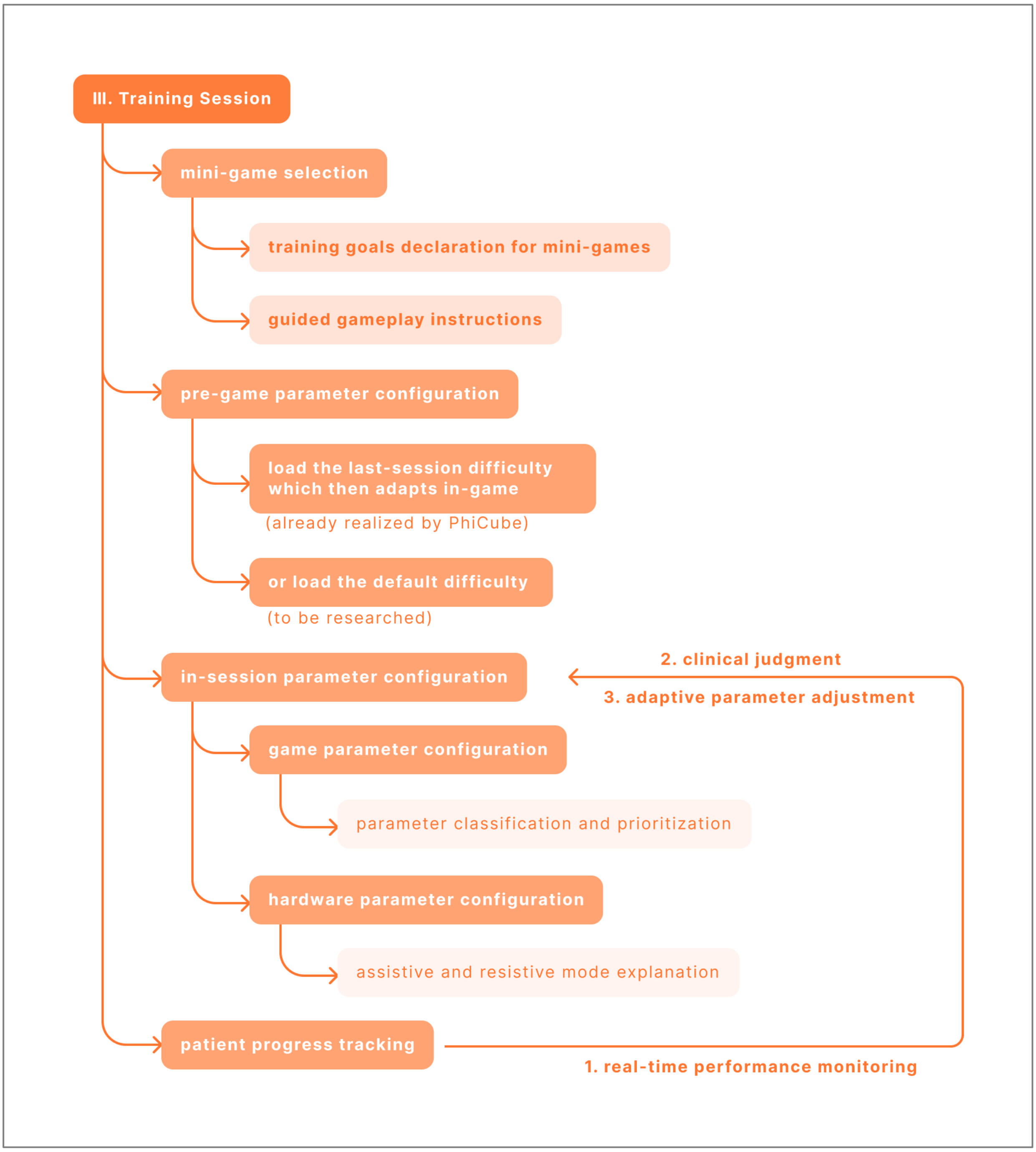

Figure 12: Proposed Therapist-Oriented IA of PhiCube – Training Session.

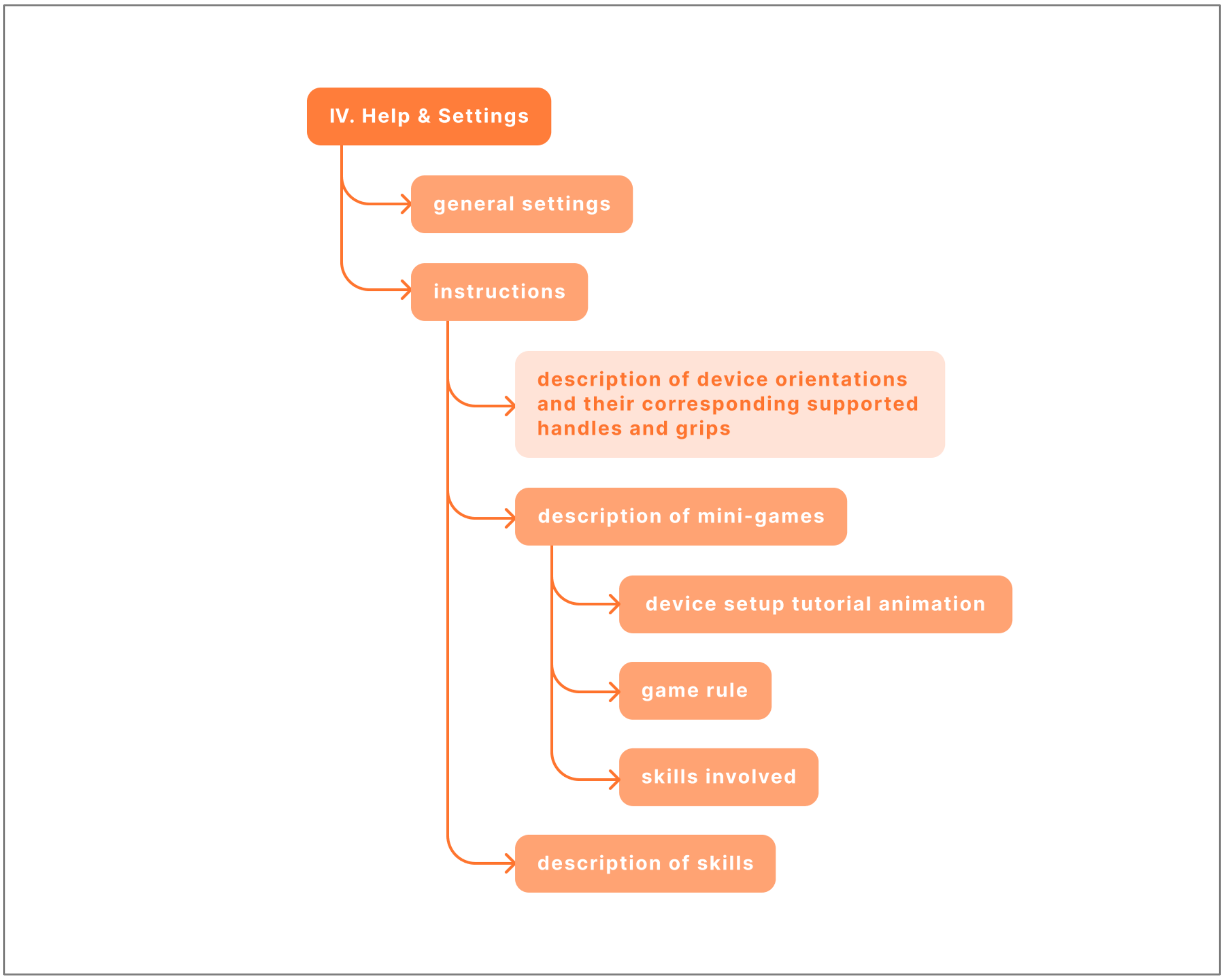

Figure 13: Proposed Therapist-Oriented IA of PhiCube – Help & Settings.

6.3 Prototype and Iteration

6.3.1 Features Prototyping

Prioritized functions have been prototyped for further iterative refinement (see Figures 14–25). Feedback from the PhiCube development team highlights the need to define appropriate default difficulty configurations in-game, which reveals a critical direction for future study.

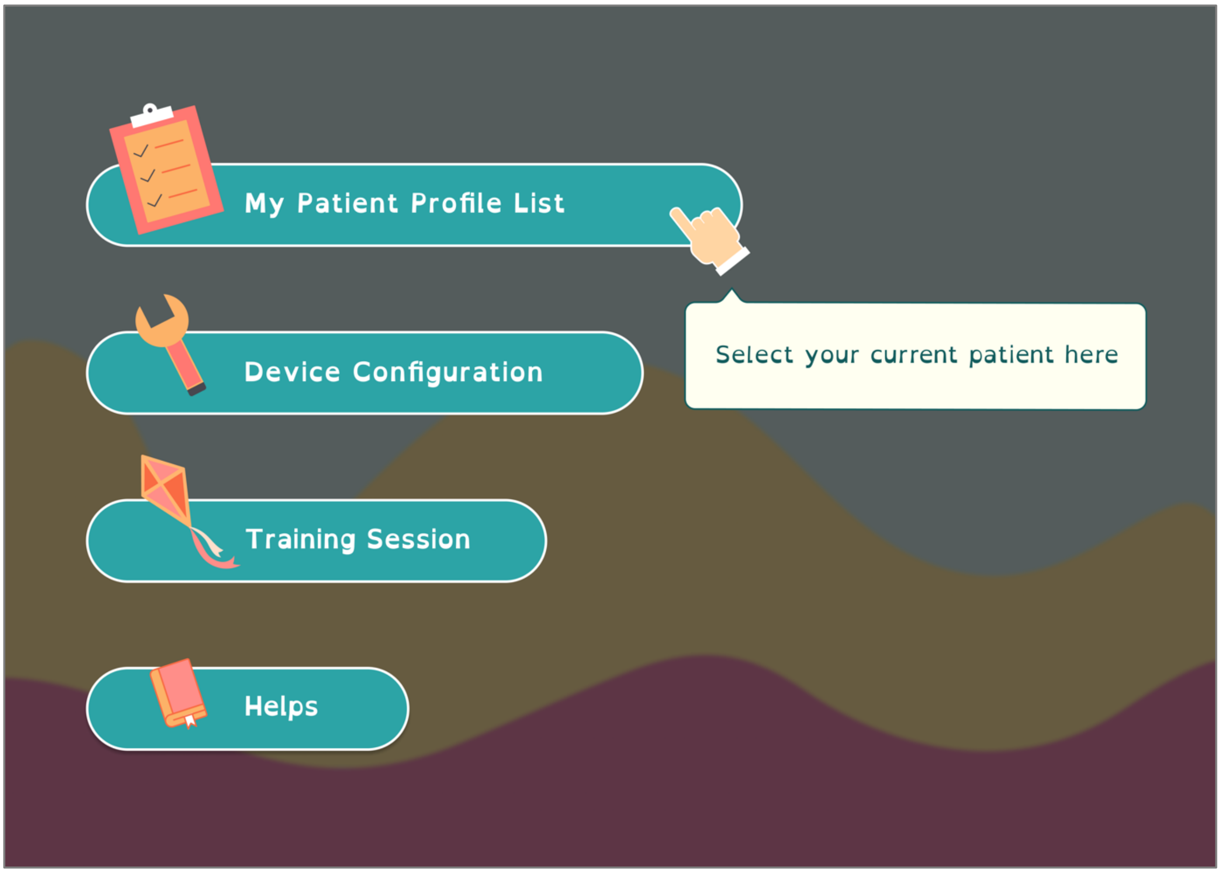

Figure 14: Hierarchized main menu prototype.

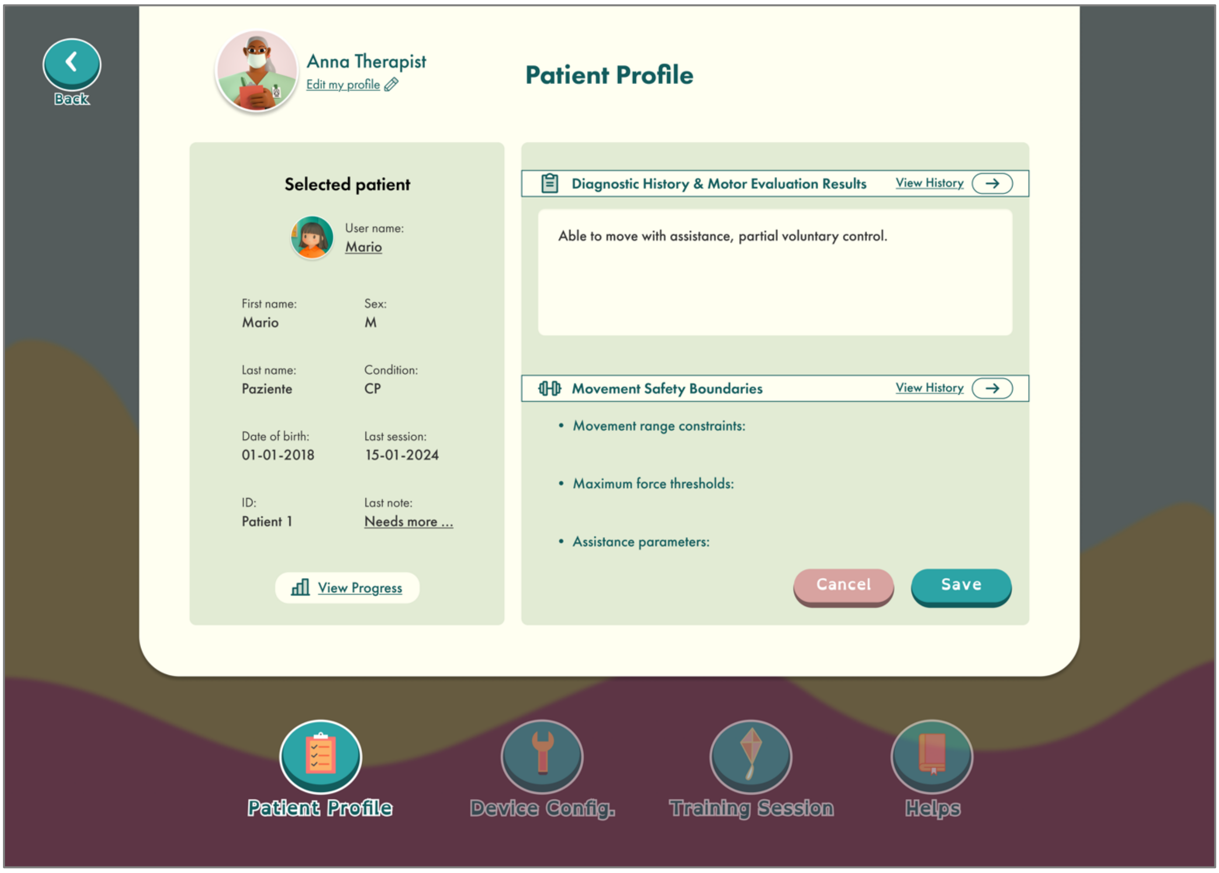

Figure 15: Patient profile template prototype.

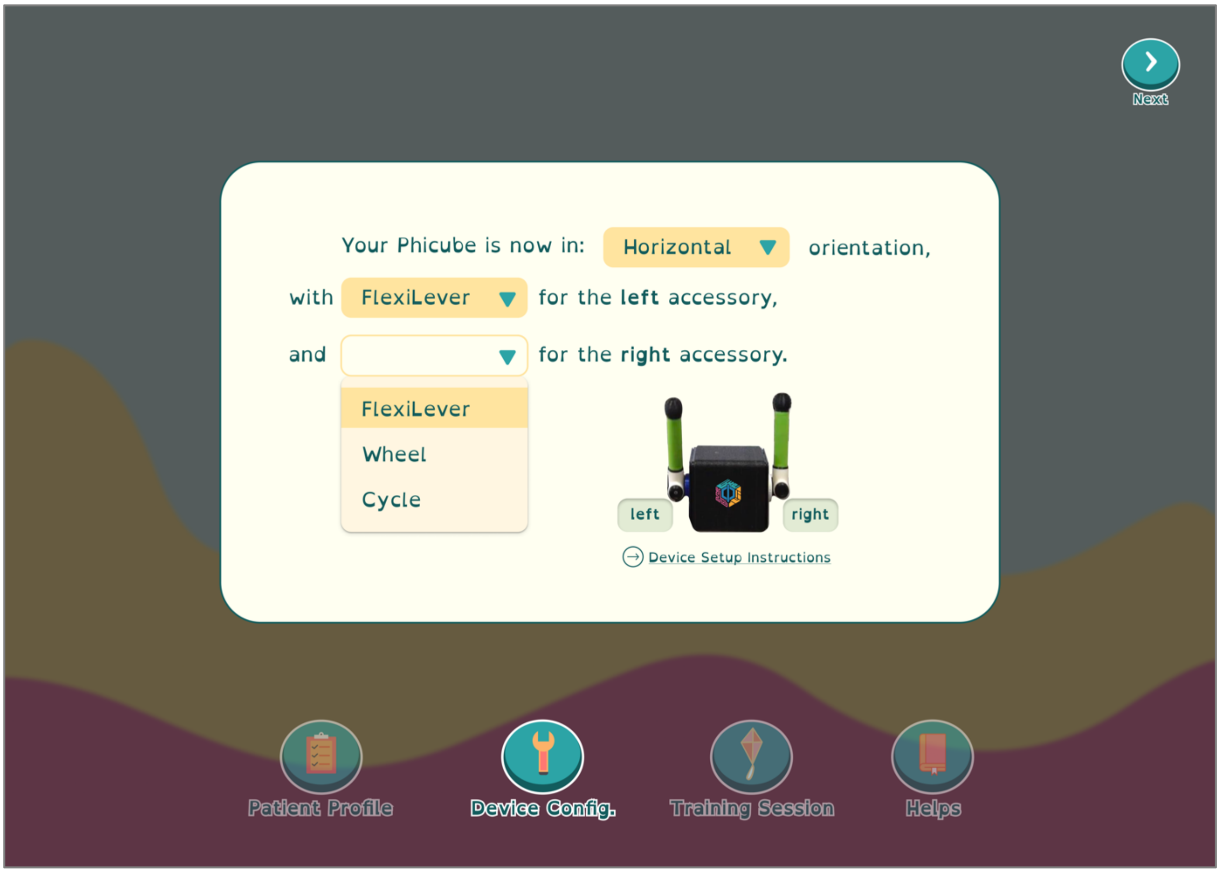

Figure 16: Device setup interface design.

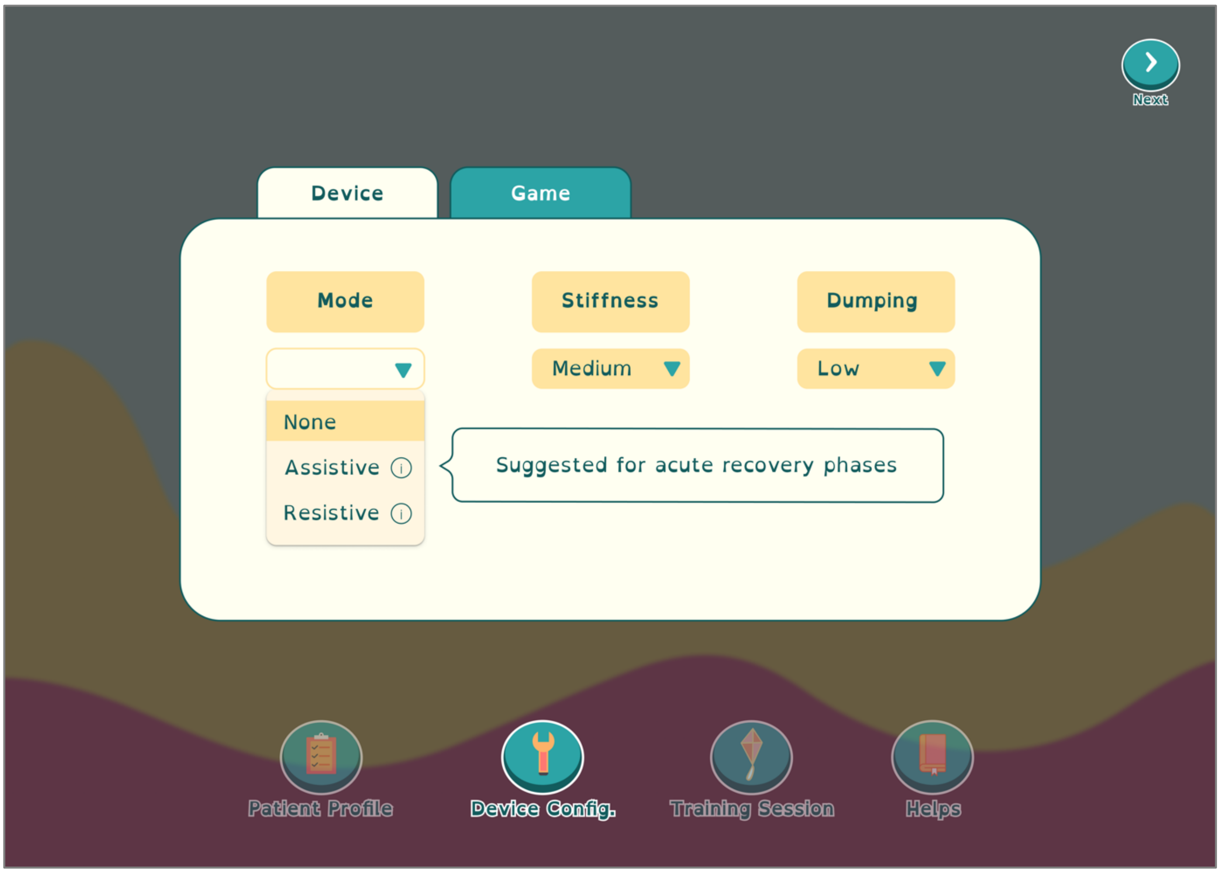

Figure 17: Hardware configuration interface design.

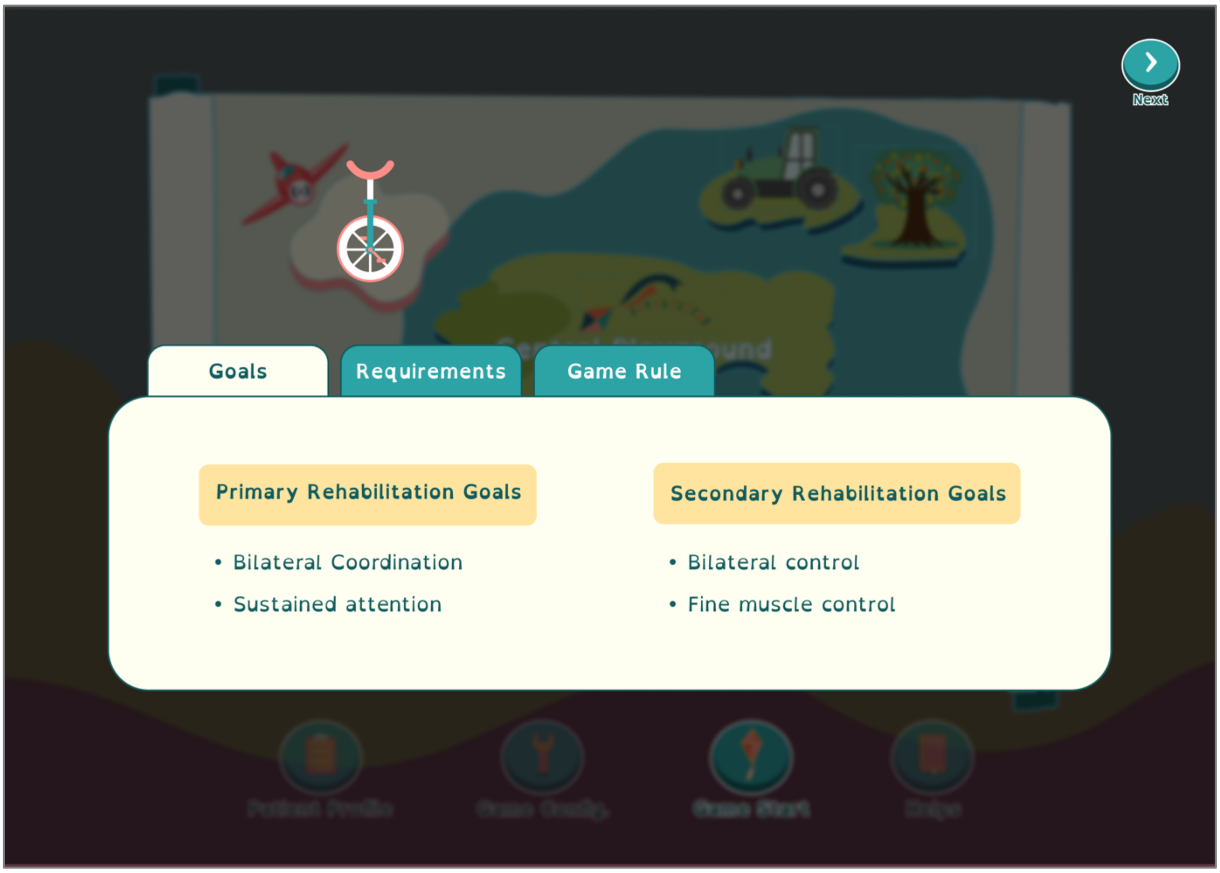

Figure 18: Game-goal mapping structure.

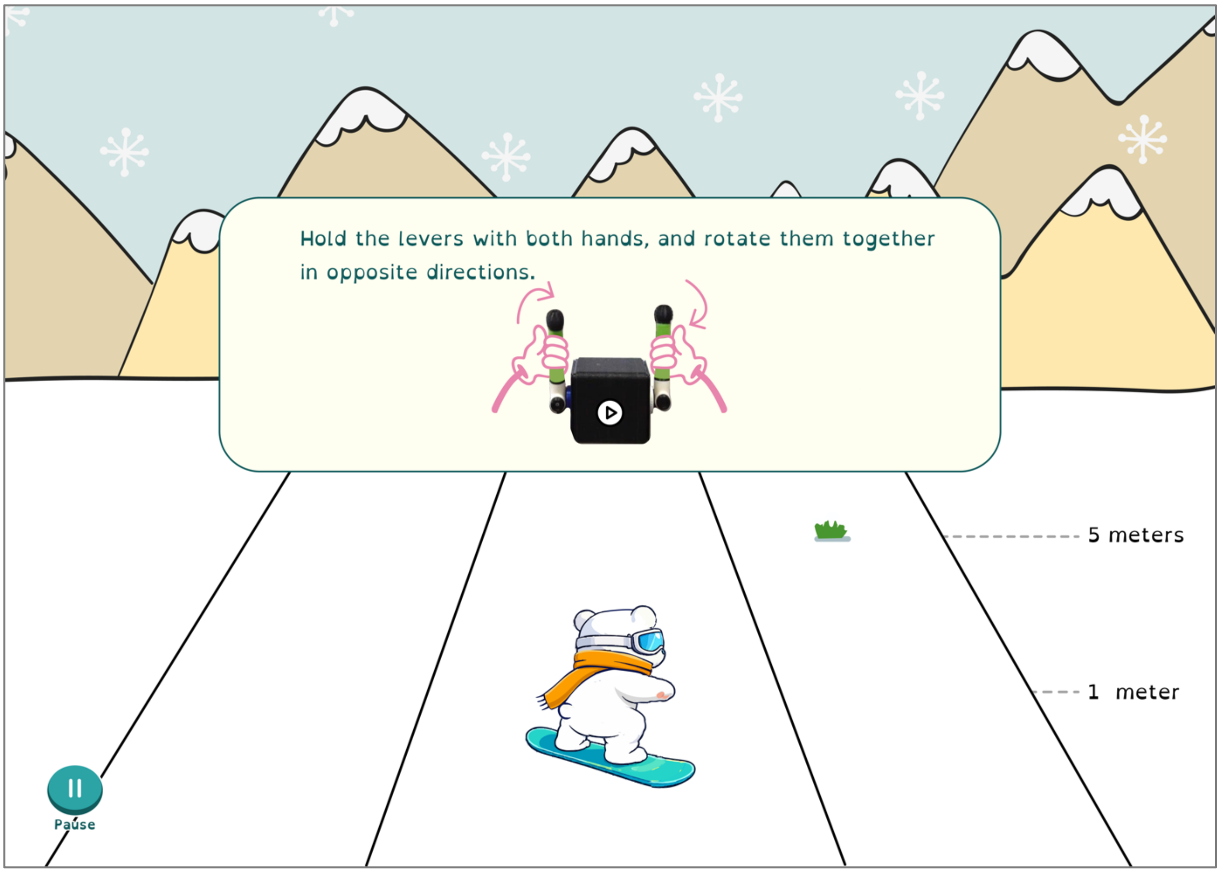

Figure 19: Guided gameplay step 1 interface.

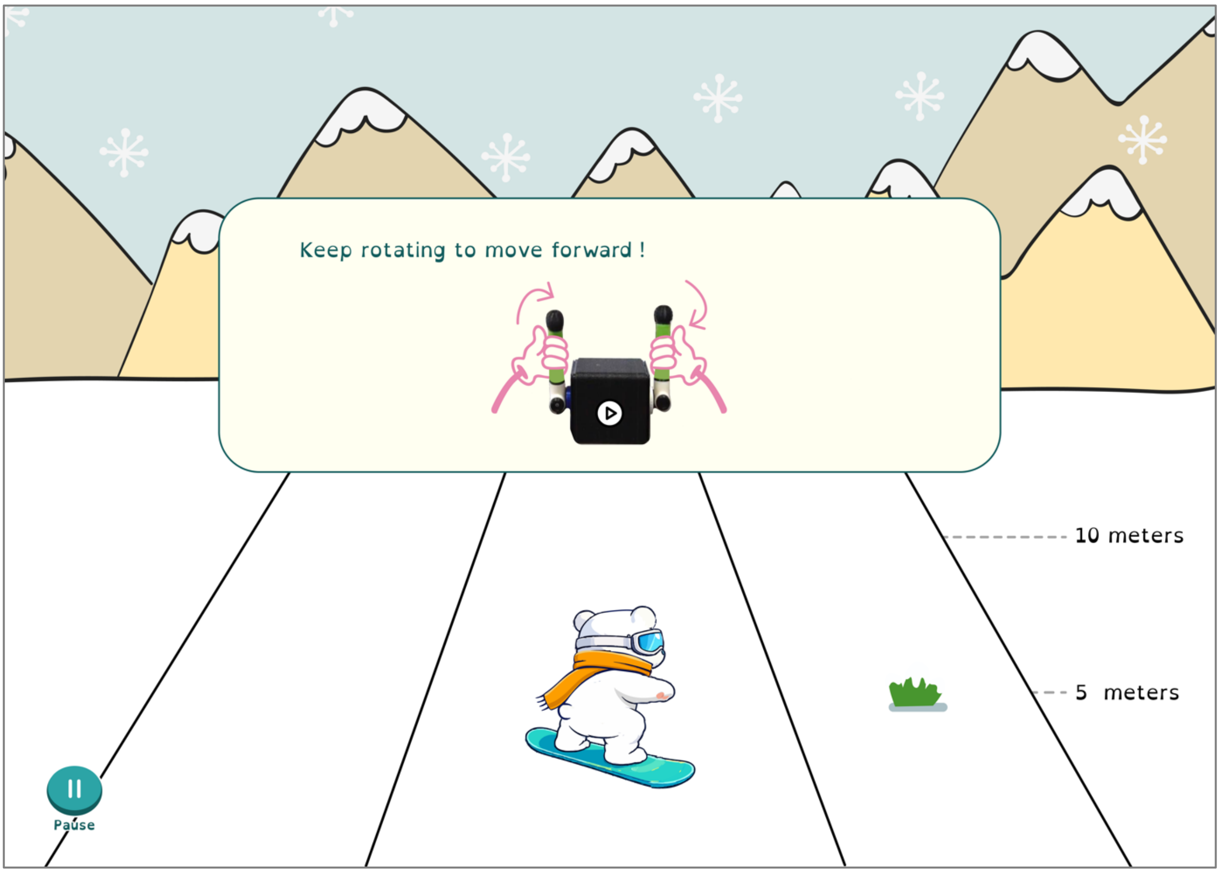

Figure 20: Guided gameplay step 2 interface.

Figure 21: Guided gameplay step 3 interface.

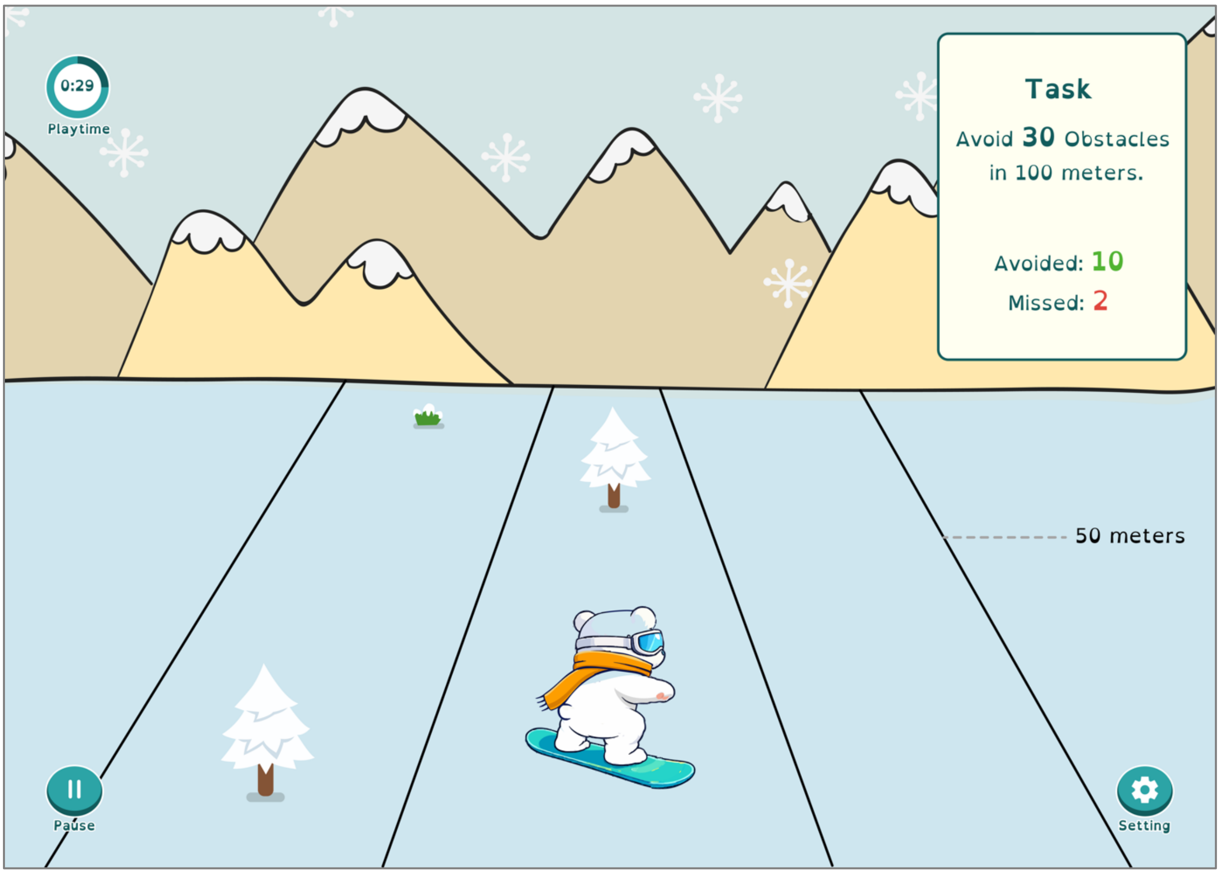

Figure 22: In-game task declaration design.

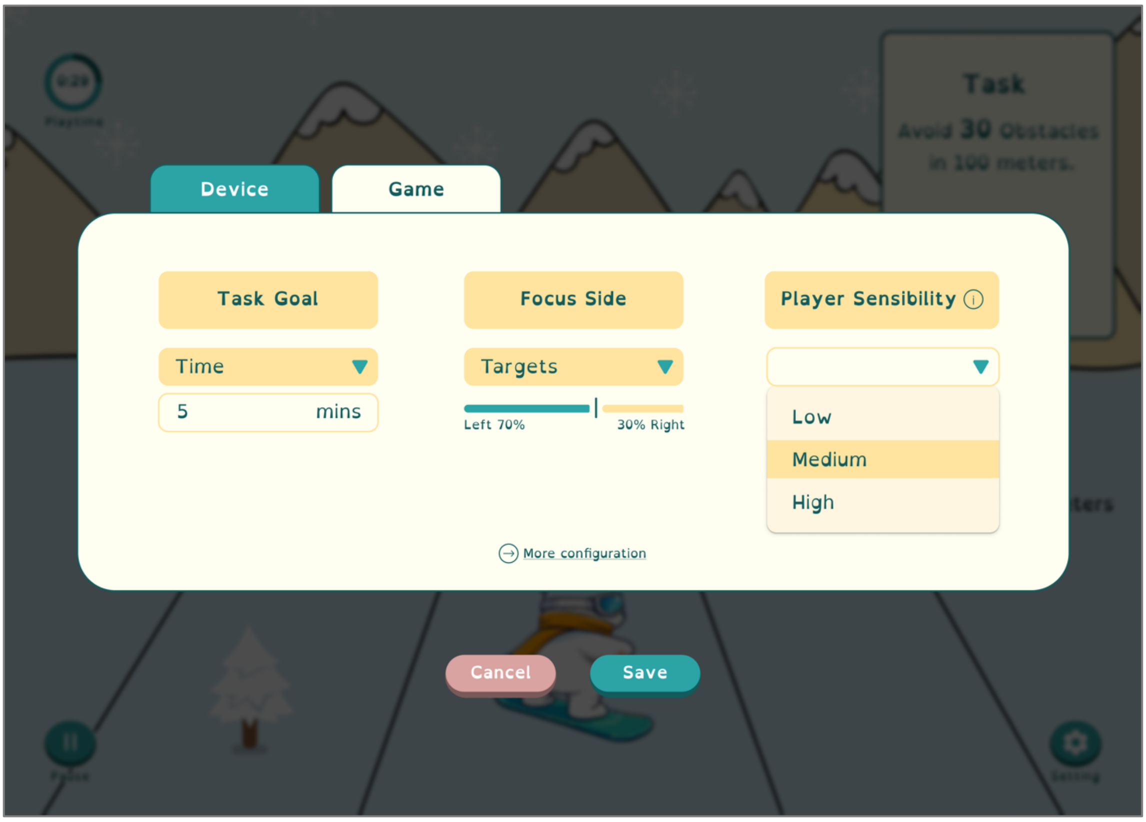

Figure 23: Game parameter adjustment interface design.

Figure 24: Mini-game description interface design.

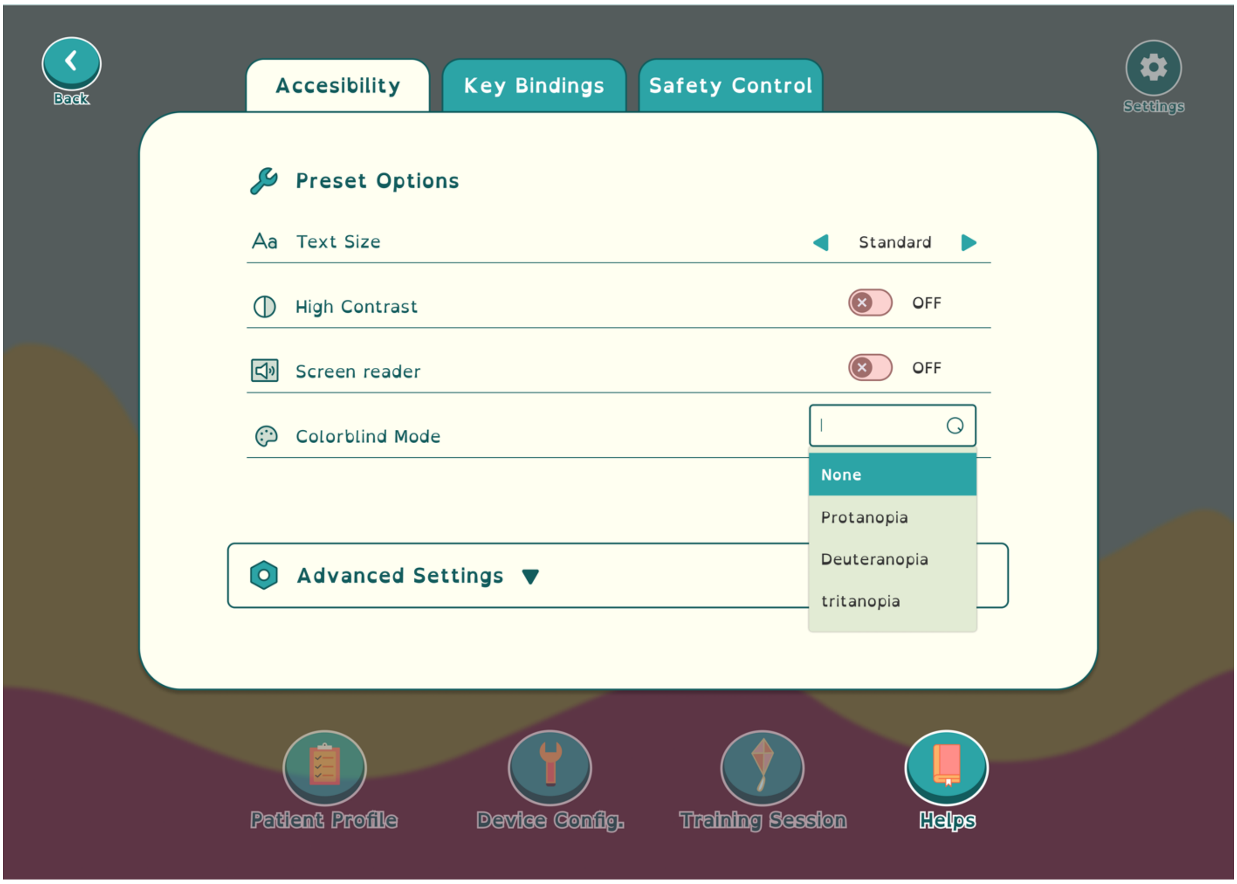

Figure 25: Accessibility interface design.

6.3.2 Verification Methods Proposal

This section presents a proposed iteration design method to verify the feasibility of the therapist-oriented PhiCube platform design, focusing on task understanding, goal representation, and parameter adjustment. The study is conceptually defined but not yet performed and aims to evaluate whether the interface supports therapists in interpreting training goals, identifying parameters with the most clinical relevance, and understanding platform-provided performance metrics. A pilot usability test with 5–8 clinical therapists is proposed, as this sample size is commonly recommended for early-stage design validation (Muratovski et al., 2022).

Using a representative training game, participants would complete three main tasks: reviewing a game task description to identify its therapeutic focus and suitable patient group; navigating the platform to locate and adjust relevant parameters during a simulated training session; and interpreting the displayed performance data from a clinical perspective. Qualitative feedback would be collected through semi-structured questions regarding the clarity of task–goal alignment, the logical organization of parameters, and the appropriateness of the interface for real clinical workflow.

Quantitative evaluation would focus on task completion time and overall system usability, measured using the System Usability Scale (SUS) upon task completion. A SUS score of 68 or higher is proposed as a threshold for acceptable usability to guide further iterative refinement. This integrated qualitative and quantitative method is designed to assess whether the therapist-oriented information architecture supports clear, efficient, and clinically appropriate interaction.

Conclusion and Limitations

This study explores design opportunities for the PhiCube platform, focusing on enhancing clinical usability and cognitive accessibility. Through user analysis and benchmarking, gaps in task classification, parameter adjustment, and clinical decision support were identified. Corresponding design interventions were proposed and prototyped, with features prioritized to align the platform structure with clinical utility. The findings provide initial insights that may support the iterative design of PhiCube platform or similar gamified pediatric rehabilitation tools.

This study is based on qualitative exploration and has not yet included clinical feedback. The proposed design focuses primarily on therapist workflows in clinical contexts, with limited attention to patient-oriented functionalities and diverse user subgroups. Future work may follow the pilot usability test design outlined in Section 6.3.2, with a small-scale evaluation involving 5 clinical therapists to validate the clinical feasibility of the proposed information architecture, refine current design proposals, and support future iterations that expand to patient-oriented features and broader user groups.

Acknowledgement

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