

Article

A Seamless Technology Integration Framework for Elderly-Centered Interactive Systems: Design, Implementation, and Validation Through the Pillow Fight System

Chor-Kheng Lim , Hung-Yu Chen and Xuan-Yu Chen

Department of Art and Design, YuanZe University, Taoyuan City 320315, Taiwan;
hungyu850331@gmail.com (H.-Y.C.); abc0983322207@gmail.com (X.-Y.C.)

* Correspondence: kheng@saturn.yzu.edu.tw

Abstract: The rapid aging of the global population has highlighted the urgent need for age-friendly technological solutions. However, our review of the existing studies revealed significant gaps between elderly users' needs and the current smart technology products. While previous research has explored various aspects of elderly technology design, our systematic analysis indicated limitations, in terms of integrated frameworks, empirically validated interaction models, and long-term effectiveness evaluation. This study proposes a seamless technology framework for the development of elderly-centered interactive systems—named Pillow Fight—which we validated through a mixed-methods study of an innovative intergenerational gaming system. This research was conducted in two phases across 34 sites, with 1997 participants. Phase one (n = 659) established the framework's effectiveness through systematic field testing, while phase two (n = 1338) validated its scalability and long-term benefits. The results highlight significant improvements in system usability scores (SUS), from individual use (77.85) to group activities (85.32), with intergenerational interaction achieving the highest scores (92.12). The integration of health monitoring features further enhanced learnability (94.12) usability (82.15). This study contributes to the design of technology for the elderly through (1) establishing an integrated theoretical framework for seamless technology integration, (2) developing and validating innovative intergenerational interaction models, and (3) providing empirical evidence through systematic field studies. These contributions could advance both theoretical understanding and practical applications while maintaining high user-friendliness.

Keywords: elderly technology; intergenerational interaction; human–computer interaction; mixed method; seamless technology integration; smart interactive system



Citation: Lim, C.-K.; Chen, H.-Y.; Chen, X.-Y. A Seamless Technology Integration Framework for Elderly-Centered Interactive Systems: Design, Implementation, and Validation Through the Pillow Fight System.

Appl. Sci. **2024**, *14*, 11306.

<https://doi.org/10.3390/app142311306>

app142311306

Academic Editor: Gianluigi Ferrari

Received: 14 November 2024

Revised: 27 November 2024

Accepted: 2 December 2024

Published: 4 December 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The rapid aging of the global population and the advancements of digital technology have highlighted the urgent need for age-friendly technological solutions. According to the Market Intelligence and Consulting Institute [1], the population of people aged 65 and above now exceeds 17% in Taiwan, indicating its transition to an aged society. Liu and Chang [2] conducted a systematic review demonstrating that smart home technologies can effectively assist the elderly in aging at home and can improve their quality of life. Despite the recognized potential of smart technologies in supporting the elderly at home, significant challenges remain in their practical implementation. The current development efforts face three fundamental issues. Firstly, existing products often emphasize technological capabilities, without sufficient consideration of the user experience. Secondly, design approaches frequently lack systematic consideration of elderly users' psychological needs. Thirdly, the absence of comprehensive design frameworks has led to fragmented development efforts. However, Chen and Lin [3] found that despite the active development of smart technology products by tech companies and medical institutions their adoption remains limited. Liao and Wu [4] further pointed out that the core issue lies not in the “technology”

but in the “design”, noting that many existing elderly technology products focus primarily on technical aspects, while neglecting usability. Zhou et al. [5] examined the elderly’s acceptance of AI medical services from the perspective of the Technology Acceptance Model (TAM), revealing that beyond usability and utility, trust and anxiety levels are also key factors affecting technology acceptance. This finding extends the traditional TAM perspective while highlighting the importance of human-centered design approaches in elderly technology development.

These challenges highlight the need for a systematic approach to elderly technology development. Seeking to address these challenges and research gaps systematically, this paper is organized as follows. Section 2 presents the theoretical background and related work, incorporating perspectives from ubiquitous computing, ecological psychology, and intergenerational technology applications. Section 3 describes our research methodology, including the design framework’s construction, system development, and field study methods. Section 4 details our experimental environment and presents comprehensive results from two phases of field studies with 1997 participants across 34 sites. Finally, Section 5 discusses our findings and their implications, examines the research limitations, and proposes future research directions, followed by our conclusions.

The theoretical foundation of this study integrates three key perspectives: ecological psychology, social interaction theory, and affective computing. Gibson [6] proposed the ecological approach theory, emphasizing that human perception and behavior are directly connected, forming what he termed “affordance”—the environment’s natural ability to guide appropriate interactive behaviors. Murphy [7] applied this theory to human–computer interaction research, discovering that when technological interfaces align with users’ natural perceptual patterns, users can operate the technology correctly without undergoing complex learning processes. In terms of social interaction, Kane and Cook [8] revealed that social isolation not only affects psychological health but may also accelerate cognitive decline in dementia patients. This finding highlights the importance of timely intervention and social connection establishment. Bengtson and Ferraro [9] emphasized that intergenerational relationships significantly impact the elderly’s psychological well-being, while a lack of intergenerational interaction may deepen their social isolation and psychological loneliness. Stevens [10,11] and Bedford [12,13] further noted that emotional connections with family members contribute significantly to elderly well-being, with Fin-german et al. [14] highlighting how 21st-century social changes have emphasized the importance of emotional connections in elderly mental health.

Through analysis of the literature, three significant research gaps in elderly technology development have been identified. Firstly, the current research lacks an integrated design framework. As Zhou et al. [5] noted, existing studies often focus on single aspects, such as interface design or functional development, lacking a framework that integrates human needs, interaction design, and technical implementation. This fragmented research approach struggles to effectively address the overall challenges of elderly technology use. Secondly, intergenerational interaction design principles lack systematic empirical support. While Al Mahmud et al. [15] and Vanden Abeele and De Schutter [16] affirm the value of intergenerational interaction, there remains a lack of large-scale, long-term empirical studies validating specific mechanisms for the design and implementation of intergenerational interaction. Thirdly, effective long-term benefit evaluation mechanisms are lacking. Most existing research focuses on evaluating the short-term usage effects, as seen in Lee and Hong’s [17] study, primarily concerning initial acceptance. However, systematic evaluation research on elderly technology products’ sustained usage, long-term social impacts, and health promotion effects remains largely absent.

Based on these research gaps, this study aimed to develop and validate a seamless technology framework for elderly-centered interactive systems. The research objectives were threefold: (1) to establish an integrated design framework that transforms human needs into concrete design elements, (2) to develop innovative intergenerational interaction models, and (3) to validate the framework’s effectiveness through systematic field studies.

This study introduces a new design—the “Pillow Fight” intergenerational interactive system [18–20]—which received global recognition at the 2019 Stanford Center on Longevity Design Challenge. The system’s development can be traced back to interactive memory product design research in digital fabrication [21], demonstrating continuous exploration in integrating technology with human needs.

This study’s innovative contribution is manifested in three aspects. Firstly, in terms of design thinking, we propose the concept of “seamless technology”, extending Weiser’s [22] vision of ubiquitous computing. This concept emphasizes (a) hiding technological components within daily objects to reduce users’ resistance, (b) maintaining the original user experience and emotional connection, and (c) achieving seamless integration between technological functions and natural behaviors. Secondly, in terms of technical application, we have developed a soft sensing technology based on the Nielsen Norman Group’s [23] design guidelines, combined with Khan et al.’s [24] sensing technology application principles. Thirdly, in terms of practical validation, we present a two-phase field study, which was conducted across 34 sites with 1997 participants, employing both quantitative tools (SUS usability scale) and qualitative methods (observations and interviews), to evaluate the system’s effectiveness.

2. Theoretical Background and Related Work

The theoretical foundation of this study integrates perspectives from ubiquitous computing, ecological psychology, and natural mapping principles. This integration forms a comprehensive framework for the design of elderly-centered technology that can be seamlessly integrated into daily life.

2.1. Theoretical Foundation for Seamless Technology and Human–Computer Interaction

The seamless technology integration framework proposed in this study synthesizes multiple theoretical perspectives and empirical findings in human–computer interaction, particularly focusing on elderly users’ needs and interaction patterns.

This framework is primarily based on three essential theoretical foundations, from which three core design principles are derived. Firstly, it builds upon Weiser’s [22] theory of ubiquitous computing. Weiser emphasized that the most profound technologies are those that disappear into the fabric of everyday life. This perspective directly inspired the establishment of our “physical invisibility” principle, in which technological components must be completely hidden within carrier objects while maintaining their original appearance and tactile qualities.

Gibson’s [6] ecological psychology theory provides the second theoretical pillar. Gibson’s concept of “affordance” emphasizes the natural guiding effect of the environment on behavior, which directly leads to our principle of “usage continuity”: newly added technological functions should not interrupt or alter users’ existing habits. For example, a handle provides “graspability” and stairs provide “walkability”. These inherent properties allow elderly users to intuitively understand how to interact with such objects, effectively lowering the learning threshold for those who may not be experienced with technology. Affordance refers to the inherent properties of objects that naturally suggest their possible uses without requiring extensive learning. For elderly users, leveraging these affordances by integrating technology into familiar objects can significantly reduce the learning curve and facilitate intuitive interaction. Murphy’s [7] empirical findings in human–computer interaction research further highlight the importance of this principle.

Thirdly, Norman’s [25] natural mapping theory provides the final theoretical foundation for the framework. Norman emphasizes that interface design should correspond to users’ mental models, particularly supporting our principle of “emotional fidelity”: technological integration must maintain the original emotional connection between users and objects. To further support this principle, the concept of Memory of Things (MoT) [21] highlights the emotional value that familiar objects carry for elderly users. Csikszentmihalyi and Rochberg-Halton [26] argue that certain objects in our daily lives embody personal

memories and emotional connections. By embedding technology into such familiar objects, it becomes easier for elderly users to accept and emotionally connect with the technology, thereby enhancing the emotional fidelity of the interaction. This is especially important for elderly users, as it suggests that technological interactions should build upon existing life experiences, rather than requiring the learning of entirely new paradigms.

This theoretical foundation is further strengthened by recent research in elderly-specific interface design. Ijsselstein et al. [27] demonstrated that the age-related decline in visual, auditory, and physical capabilities significantly impacts elderly users' acceptance of and ability to use traditional computer interfaces. Their findings emphasize the need for specialized design approaches that accommodate these physiological changes. Building on this understanding, Gerling et al. [28] and Chesham et al. [29] established crucial design principles for elderly users, emphasizing visual interface legibility, operational process simplicity, and feedback mechanism immediacy. These principles align closely with our framework's focus on intuitive design and simplified interaction patterns.

Particularly relevant to our approach is the work of Varesano and Vernerio [30], who demonstrated the effectiveness of tangible input devices for elderly users. Their research showed that physical interaction interfaces significantly enhance elderly users' ability to intuitively control digital systems, providing empirical support for our strategy of integrating technology into familiar daily objects.

These three core principles—physical invisibility, usage continuity, and emotional fidelity—collectively comprise the theoretical foundation of the seamless technology integration framework. They not only embody Norman's [25] natural mapping principles but extend their application to broader aspects of product design, while incorporating specific considerations regarding elderly users' needs and capabilities. This comprehensive theoretical framework provides a solid foundation for the development of technological products that can be naturally integrated into elderly users' daily lives, while addressing their unique interaction requirements. By synthesizing Gibson's ecological psychology, Norman's natural mapping, and the Memory of Things concept, our seamless technology integration framework provides a holistic approach that not only ensures physical invisibility and continuity in user habits but also emphasizes the emotional connection between users and objects. This integrated approach is especially vital for elderly users, as it allows technological products to become a natural part of their daily routines, while minimizing any psychological or cognitive discomfort associated with new technologies.

2.2. Sensing Technology and Soft Computing Applications

The rapid advancement of wearable technology has led to a shift from purely physiological monitoring to emotional awareness and social interaction. According to Gartner's [31] market research, this evolution reflects the growing recognition of the need to integrate social and emotional elements into technological solutions for the elderly.

Project Jacquard [32] represents a significant breakthrough in soft sensing technology integration. By successfully incorporating touch control functionalities into traditional fabrics, while maintaining their original textures and wearing experiences, it demonstrates the feasibility of seamless technology integration. This project's success lies in three key aspects: (1) material properties—maintaining the warmth, comfort, and flexibility of traditional textiles; (2) interaction design—developing natural operation methods with immediate feedback; (3) technical integration—achieving the seamless integration of technology within daily objects.

Khan et al. [24] systematically reviewed various sensing technologies for elderly care applications, particularly focusing on fall detection and activity monitoring. Their analysis of both wearable sensors and environmental sensors provides valuable insights into the technical requirements for elderly-centered design. They emphasize that successful sensing technology must balance sensitivity and comfort, particularly when integrated into daily objects.

The application of capacitive sensing in soft materials presents unique challenges and opportunities. Research has shown that careful consideration of the material properties and sensor placement is crucial in maintaining both functionality and user comfort. This is particularly important for elderly users, where comfort and familiarity with materials can significantly impact technology acceptance.

Van Erp and Toet [33] discovered that emotional touch interaction does not only exist between humans but can also be effectively established between humans and digital devices through appropriate design. This finding opens up new possibilities for interaction design, particularly in applications requiring an emotional connection. Their research supports our work's emphasis on human-centered design thinking.

2.3. Theory of Intergenerational Technology Application

Intergenerational interaction research has experienced significant theoretical development over the past two decades. In their groundbreaking research, Bengtson and Ferraro [9] pointed out that intergenerational relationships are influenced by multiple factors, including sociocultural backgrounds, family structures, and personal experiences. They established a life course perspective framework within intergenerational interaction theory, emphasizing the dynamic and complex nature of intergenerational relationships. This theoretical framework provides an important foundation for an understanding of intergenerational relationships in modern society.

Fingerman et al. [14] further expanded this theoretical framework, particularly focusing on intergenerational relationships in the 21st century digital age. Their research found that while technological development presents new challenges for intergenerational relationships it also creates new opportunities. From one perspective, digital divides may deepen generational gaps; from another, appropriately designed technological products can become effective mediators of intergenerational connections.

Wang and Wu [34] focused their research on intergenerational technology learning patterns. They found that through appropriate technological mediation, intergenerational learning can not only promote elderly digital literacy but also strengthen intergenerational emotional connections. This was particularly evident in gamified interaction scenarios, where different generations could establish more natural and lasting interactive relationships.

Chen and Huang's [35] recent research further confirmed that good intergenerational communication can effectively reduce elderly users' fear of technology. Their proposed "Intergenerational Technology Acceptance Model" explains how intergenerational interaction influences elderly users' technology-related motivation and behavior, providing theoretical guidance for the design of technological products that promote intergenerational interaction.

2.4. Related Work and Research Gaps

Through the literature analysis, three significant research gaps have been identified in elderly technology product development:

1. The current research lacks an integrated design framework. As Zhou et al. [5] pointed out, existing studies often focus on single aspects, such as interface design or functional development, lacking a framework that integrates human needs, interaction design, and technical implementation. This fragmented research approach struggles to effectively address the overall challenges of elderly technology use.
2. Design principles for intergenerational interaction lack systematic empirical research support. While Al Mahmud et al. [15] and Vanden Abeele and De Schutter [16] have affirmed the value of elderly–children co-play, there remains a lack of large-scale, long-term empirical research validating specific mechanisms for the design and implementation of intergenerational interaction. Khoo et al. [36] developed the intergenerational interactive game "Age Invaders", innovatively integrating a physical interactive space with virtual game elements to create a natural interactive environment for grandparents and grandchildren. According to Al Mahmud et al.'s research analysis, elderly users show stronger gaming motivation when playing with

their grandchildren. Additionally, physical interactive interfaces and puzzle-type game content help elderly users to interact with others in a joyful atmosphere while enhancing their social capabilities.

3. Effective long-term benefit evaluation mechanisms are lacking. Most existing research focuses on evaluating short-term usage effects, as seen in Lee and Hong's [17] study, primarily concerning initial acceptance. However, systematic research on elderly technology products' sustained usage, long-term social impacts, and health promotion effects remains largely lacking.

The identification of these research gaps through our systematic review of the existing literature not only emphasized the research questions proposed in the Introduction, but also highlighted the importance of establishing an integrated design framework. While previous studies have made valuable contributions to elderly technology design, our analysis reveals the need for a more comprehensive approach. Particularly in promoting intergenerational interaction and enhancing emotional connections, the synthesis of the existing research findings provides clear directions for future elderly technology product development and opens up new possibilities for advancement in this field.

3. Research Methods

3.1. Research Design Framework

This study employed mixed-methods research and a research-through-design methodology. The selection of these research methods was based on three major theoretical foundations:

1. As Creswell and Plano Clark [37] point out, mixed-methods research provides a more comprehensive research perspective when dealing with complex elderly technology usage issues. This study employed a concurrent mixed-methods design, simultaneously collecting and analyzing both quantitative and qualitative data to gain a holistic understanding of elderly technology use. Quantitative methods (such as the SUS scale) provide objective measurements of systems' effectiveness, while qualitative approaches (including observations and interviews) offer deeper insights into user experiences and interaction patterns. This concurrent approach enabled us to validate the findings through methodological triangulation, while capturing the richness and complexity of user interactions in natural settings.
2. We adopted the research-through-design methodology proposed by Zimmerman et al. [38]. This methodology emphasizes that the design process itself is an important path for knowledge production, particularly suitable for exploring how to transform human needs into concrete design elements. Through iterative design research methods, this study continuously optimized the design principles.
3. To ensure the practical applicability of the research findings, this study adopted multi-site empirical research methods based on Maxwell's [39] ecological validity theory. This method ensured the validity of the research findings in real-world usage environments, which is particularly important when investigating intergenerational interaction issues that require the consideration of complex social contexts.

This study was divided into three major phases:

1. Design framework construction phase: Focusing on establishing theoretical foundations through a systematic literature review and preliminary user research to develop an integrated design framework.
2. System development phase: Using this framework to guide the design and implementation of the "Pillow Fight" system.
3. Field study phase: Divided into two stages, with the first stage focusing on the preliminary validation of the design framework and the second stage conducting an in-depth effectiveness evaluation to systematically validate the research outcomes.

3.2. Pillow Fight System: Design Methods

For the design of the “Pillow Fight” system, this study established a systematic methodological framework. In terms of interface design, we adopted a user-centered design method, which included three systematic phases: user research, interface prototyping, and usability evaluation. Each phase employed standardized evaluation tools to ensure the scientific validity of the design decisions. In terms of sensing technology research methods, we employed experimental research methods for the development of soft sensing technology. The research methods included three main aspects:

- Material property research;
- Sensing performance testing;
- User experience evaluation.

Material property research adopts standardized testing procedures; sensing performance testing uses systematic performance evaluation methods; and user experience evaluation combines both quantitative and qualitative evaluation tools. System integration research adopts a modular research method, dividing the system into three research modules:

- A sensing module;
- A communication module;
- An application module.

Each module employs independent research methods for development and testing, followed by systematic integration testing methods to ensure module synergy. The entire research process adopts iterative testing methods, optimizing the system’s performance through continuous testing and improvement. The iterative testing follows a three-stage cycle:

1. Prototype testing—examining basic functionalities and usability;
2. User testing—evaluating the actual usage experience;
3. Field testing—validating the practical application effects.

Each cycle is optimized based on feedback from the previous stage, ensuring that the designs are continuously improved so as to better meet the users’ needs.

3.3. Field Study Methods

This study employed systematic field research methods to validate the practicality and actual application effects of the design framework. The field research design adopted a multi-phase, multi-site research strategy to ensure the reliability and completeness of the research findings.

3.3.1. Research Site and Participant Selection Methods

The selection of the sites and participants followed systematic sampling methods. For site selection, the researchers collaborated with the Hongdao Senior Citizens’ Welfare Foundation, adopting purposive sampling based on three theoretical principles. The first was the principle of geographical representation. Based on Maxwell’s [39] external validity theory, the research sites needed to cover different regional characteristics, including metropolitan, urban, and rural areas, to ensure the inferential value of the research results. The second was the principle of user group heterogeneity. According to Norman’s [25] user research theory, the research subjects needed to include users with different socioeconomic backgrounds and health conditions to comprehensively reflect the needs of different user groups. Based on the users’ physical and mental functional status, three main research groups were established:

- A healthy elderly group with complete self-care abilities and cognitive functioning in daily life;
- A sub-healthy elderly group requiring partial life assistance, with mild cognitive decline;
- A dementia elderly group requiring professional care and assistance, with significant cognitive decline.

The third was the principle of site type diversity. According to Al Mahmud et al.'s findings [15] on intergenerational interaction, the types of sites influence the interaction patterns and effects. Therefore, the research sites covered five functional types:

- Home care visit points—research sites providing home services;
- Home service centers—research environments providing home care services;
- Day care centers—research locations providing daytime care services;
- Community stations—research bases providing community activity services;
- Cognitive leisure stations—professional venues providing cognitive promotion activities.

3.3.2. Data Collection and Analysis Methods

This study established a systematic framework for data collection and analysis, integrating qualitative and quantitative research strategies. For the quantitative data collection, three standardized research tools were employed.

The first was the System Usability Scale (SUS). The SUS scale was chosen for its high reliability and validity and its particular suitability for the evaluation of new forms of interactive systems. The scale's application follows standardized procedures to ensure consistency in data collection.

The second was a user behavior recording system. Based on the behavioral analysis framework proposed by Gerling et al. [28], a systematic behavior recording method was established to collect objective data on usage frequency, duration, and interaction patterns.

The third comprised standardized questionnaire tools. The questionnaire design adopted the technology acceptance evaluation framework developed by Lee and Hong [17], integrating indicators for user satisfaction and acceptance. For qualitative data collection, this study employed three complementary research methods.

The first was participatory observation. Based on Gibson's [6] ecological psychology theory, structured observation records were designed to systematically document the users' natural interaction behaviors.

The second was semi-structured interviews. The interview framework was designed based on Patton's [40] qualitative research principles, ensuring both depth and breadth in data collection.

The third was video recording. A systematic video recording protocol was adopted to ensure the complete documentation of the interaction process and details.

3.3.3. Data Analysis Methods

Through this research, a systematic data analysis framework was established, focusing on three main aspects. For the system usability analysis, we employed the standardized SUS scale for evaluation, analyzing both the system's learnability and usability. This analysis method effectively measured the system design's practicality and provided a concrete basis for improvement.

In terms of the usage context analysis, this study particularly focused on comparing group and individual usage scenarios. Through a six-dimensional evaluation framework, we systematically analyzed the system's effectiveness in different contexts, including its attractiveness, ease of use, and acceptance. Additionally, through field observations and data analysis, we identified major usage pattern types to understand the system's applicability in different scenarios.

For the effectiveness evaluation, this study emphasized analyzing the implementation effects of intergenerational interaction. Through comparing the system optimization results across different phases, we evaluated the substantial benefits of design improvements. Furthermore, in the second phase of the research, we incorporated a health monitoring data analysis to validate the system's health promotion effects among users. This multi-dimensional analysis approach enabled a more comprehensive assessment of the system's practical application value.

Table 1 presents a comprehensive overview of the research methodology, illustrating the systematic integration of the theoretical foundations, research methods, and implemen-

tation approaches across different research dimensions. This structured approach ensured the rigorous development and validation of the seamless technology framework.

Table 1. Summary of research methods and approaches.

Research Dimension	Research Method	Theoretical Foundation	Implementation Tool	Expected Outcomes
Framework construction	Mixed methods research-through-design methodology.	Creswell and Plano Clark's mixed methods. Zimmerman's research-through-design method. Maxwell's ecological validity.	Systematic literature review. Preliminary user research.	Integrated design framework.
System development	User-centered design.	Material property research. Sensing technology research. UX design principles.	Standardized testing procedures. Performance evaluation methods. Iterative testing cycle.	Pillow Fight system.
Field study	Multi-site multi-phase research.	Geographic representation. User group heterogeneity. Site type diversity.	System Usability Scale (SUS). Behavior recording system. Interviews and observations.	Framework validation.

4. Experimental Environment and Results

This study presents the findings of systematic field research and the empirical analysis of a seamless technology framework for elderly-centered interactive systems. The research was conducted in two phases: phase one involved field testing across 25 sites with 659 participants, while phase two was expanded to more diverse settings with 1338 participants. Both quantitative tools (the SUS usability scale) and qualitative methods (observations and interviews) were employed to evaluate the system's effectiveness.

4.1. Design Framework Results

4.1.1. Literature Analysis Findings

Based on our systematic analysis of the literature, this study identified three core dimensions that need to be considered in designing technology products for the elderly.

From the perspective of human–computer interaction, Gibson's [6] ecological approach theory emphasizes that environments or objects should naturally guide users' interactive behaviors. When Murphy [7] applied this theory to human–computer interaction design, the findings revealed that the learning threshold decreases significantly when the interface design aligns with the user's natural perceptual patterns. This finding supports our design approach of using daily objects as interactive interfaces.

Regarding intergenerational interaction research, Al Mahmud et al. [15] demonstrated that elderly users exhibit stronger motivation to use technological products when engaging in activities with their grandchildren. Additionally, physical interactive interfaces and puzzle-type activities help elderly users to interact in a joyful atmosphere while enhancing their social capabilities.

In terms of sensing technology applications, Project Jacquard [32] confirms that interactive materials must be more closely aligned with daily life and possess the characteristics of warmth, comfort, and flexibility to facilitate more fluid user operation.

4.1.2. Development Results for Design Framework

Based on the theoretical knowledge gained from the literature analysis, this study developed an integrated design framework addressing both psychological and functional aspects. As shown in Figure 1, the research results indicate that successful elderly-centered technology product design must simultaneously consider six key dimensions.

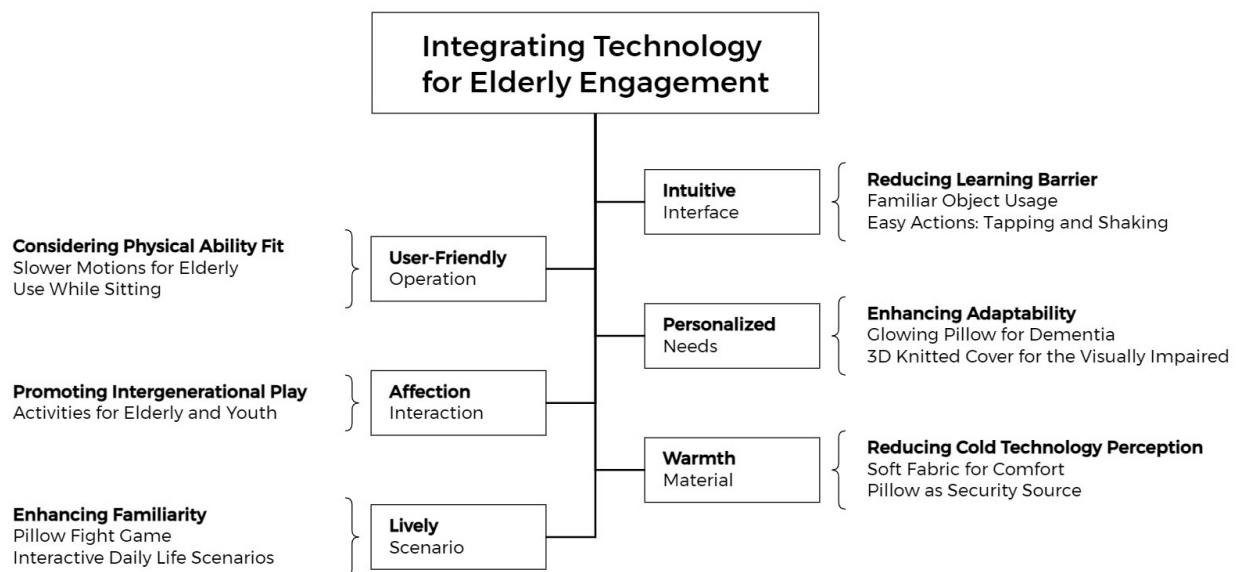


Figure 1. Integrated framework for elderly-centered technology design.

A. Psychological design elements:

1. Life integration dimension:

- Embeds technology within daily life;
- Emphasizes interaction modes based on living context;
- Research shows that developing interaction modes from daily behavioral contexts increases familiarity and promotes elderly users' affinity for technological interactive products.

2. Warmth dimension:

- Utilizes familiar objects from daily life as interaction carriers;
- Maintains the original soft tactile qualities in design;
- Research confirms that when interactive design carriers are presented as familiar daily objects and maintain the original material properties, particularly those conveying warmth, it helps to reduce elderly users' fear of technological products.

3. Emotional dimension:

- Centers on intergenerational care;
- Designs interaction methods that promote emotional exchange;
- Research results indicate that interactive technology products facilitating emotional expression or enhancing emotional exchange help to address elderly users' psychological loneliness and more readily generate strong usage motivation.

B. Functional design elements:

1. Intuitive dimension:

- Adopts familiar, intuitive interface design strategies;
- Research shows that using familiar daily objects as interactive input interfaces, coupled with simple intuitive interactive behaviors, effectively reduces the learning thresholds for elderly users;
- This simple, intuitive input interface design not only reduces the learning burden but also enhances usability by aligning with users' habits and needs.

2. Simplicity dimension:

- Considers users' physiological and psychological conditions;
- Designs interaction modes with moderate operational difficulty;
- Research shows that designing universal operation methods that can be performed with any body part effectively enhances elderly users' adaptation to

technology products, considering their declining upper- and lower-limb muscle function.

3. Personal dimension:

- Provides personalized design elements to meet different users' needs;
- Research shows that incorporating personalized elements into elderly-centered interactive technology products helps to enhance product preferences and adaptability while maintaining user engagement;
- Examples include providing customized interaction methods for different user groups (such as dementia patients or visually impaired users).

This design framework integrates psychological and functional requirements, establishing systematic guidelines for elderly-centered technology product design. In particular, the framework emphasizes the following:

1. Design thinking that originates from the living context;
2. Interaction modes that value emotional connection;
3. Adaptive designs considering users' capabilities.

This framework not only provides theoretical principles but also offers concrete design principles for subsequent system design and implementation. Additionally, this design framework directly addresses the three levels of requirements proposed in this study:

1. Basic level—achieves the natural integration of technology into daily life through dimensions related to daily life, warmth, and intuition;
2. Interactive level—promotes intergenerational interaction through emotional and personal adaptation;
3. Integration level—achieves a balance between functional requirements and emotional connection through the integration of all six dimensions.

4.2. Pillow Fight System: Design Results

Based on the established design framework, this study developed the Pillow Fight intergenerational interactive system. As shown in Figure 2, this system creates natural intergenerational interaction experiences through the integration of pillows and tablet games. The design results demonstrate how to transform the design framework into concrete interactive products while implementing the concept of seamless technology integration into daily life.



Figure 2. The Pillow Fight system in use: intergenerational gaming through pillow interaction.

4.2.1. Overall Design Architecture

The Pillow Fight system, centered on intergenerational interaction, creates natural and intuitive user experiences through physical–digital integration. The system operates based on simple interaction methods: users only need to pat the pillow to interact with the tablet games, making it particularly suitable for elderly–children co-use. As shown in Figure 3, the system architecture comprises three main components:

- Physical interaction layer (pillow sensing)—using pillows as sensing interfaces to achieve seamless technology integration;
- Digital interface layer (game application)—tablet game applications providing visual interactive feedback;

- Communication integration layer (Bluetooth connection)—Bluetooth signal connection, ensuring real-time interactive experiences.

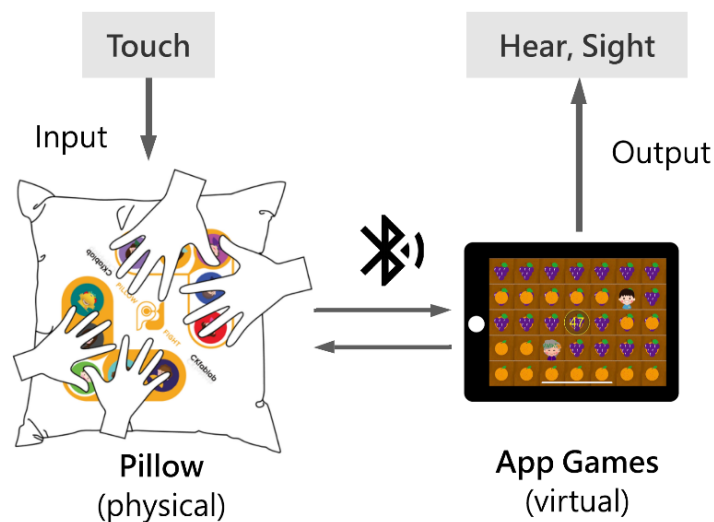


Figure 3. Pillow Fight interactive architecture: physical–digital integration for intergenerational interaction.

4.2.2. Design Implementation Results

Interface Design Implementation

This system achieves systematic innovation and optimization in interface design. As shown in Figure 4, the User Interface (UI) design framework includes four main aspects: game types, character elements, style design, and component layout. Based on the elderly interface design principles proposed by Ijsselsteijn et al. [27], a comprehensive interface design framework was established in this study.

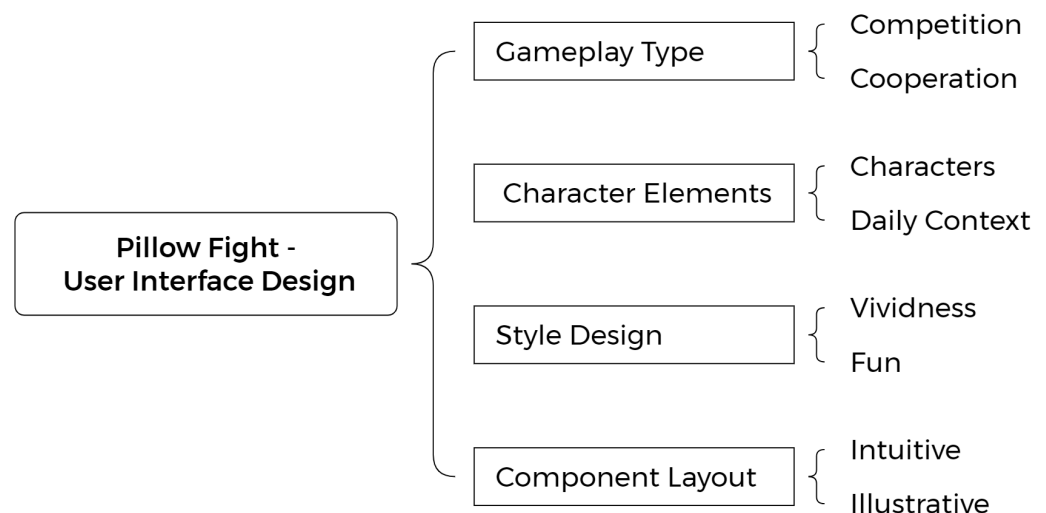


Figure 4. User interface design framework.

In terms of game type design, this study developed two main modes: competitive and collaborative (as shown in Figure 5). This dual-mode design reflects Al Mahmud et al.'s [15] findings on intergenerational interaction, effectively promoting social interaction and emotional connection during gameplay.

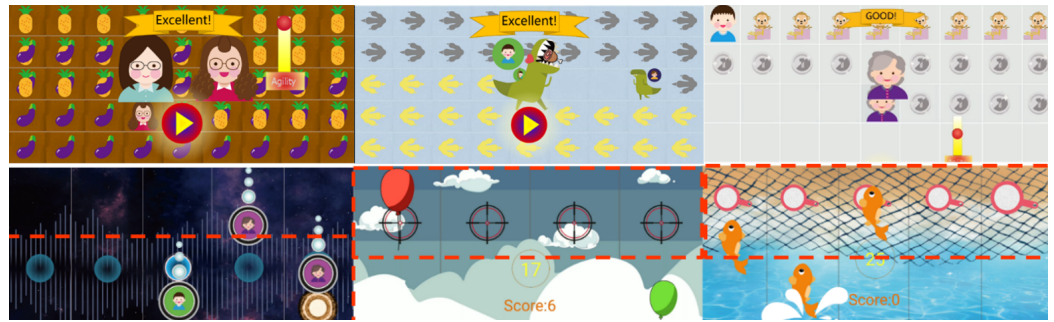


Figure 5. Competitive and collaborative game interfaces.

Regarding character element design, as shown in Figure 6, this study particularly emphasized intergenerational user identification, integrating characteristic elements from different generations while adopting daily life elements as game icons to enhance users' recognition and game integration.



Figure 6. Character design elements for intergenerational appeal.

The User eXperience (UX) design was built on a more comprehensive framework foundation. As shown in Figure 7, UX design covered five key aspects, each systematically planned and verified. Particularly in terms of physical–digital mapping, as shown in Figure 8, this study established clear corresponding relationships, enhancing users' operational confidence.

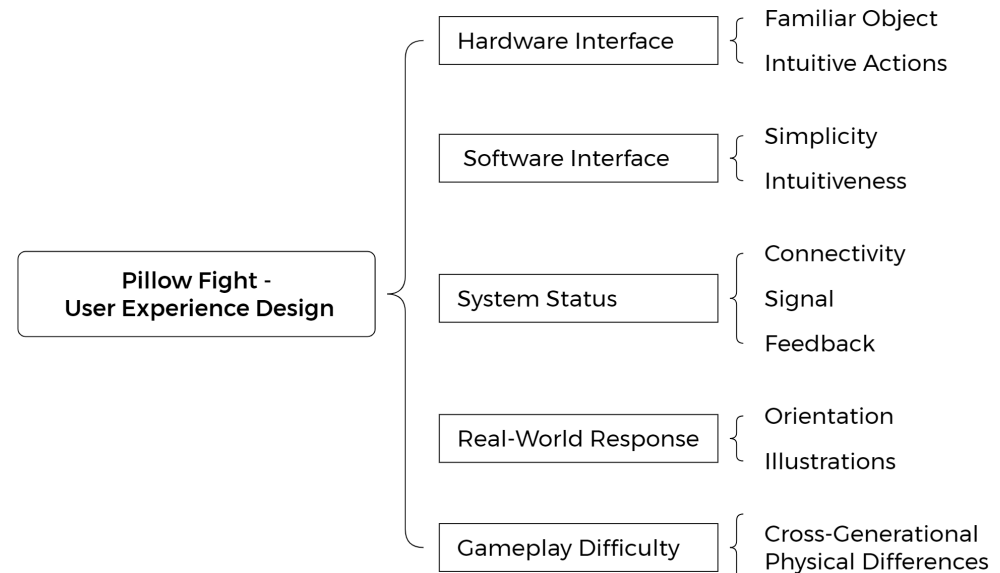


Figure 7. User experience design framework.



Figure 8. Physical–digital interface mapping: design implementation. Left: pillow cover print design with interaction areas. Right: physical–virtual mapping relationship diagram.

System Optimization Results

Through systematic design iteration, this study achieved important optimization results, covering three aspects:

1. Pillow sensing system optimization:
 - Improved image marking system to enhance operation position recognition;
 - Developed specialized pockets to resolve capacitive displacement issues;
 - Optimized sensing layer weaving method to improve accuracy and response stability.
2. Game software optimization:
 - Adjusted game speed to match elderly reaction time;
 - Expanded game content to increase entertainment value;
 - Improved operation process to enhance user experience.
3. System integration optimization:
 - Expanded tablet device compatibility;
 - Standardized equipment configuration process;
 - Enhanced system operation stability.

Particularly in terms of the interaction parameters, this system achieved two significant breakthroughs:

- It expanded the error tolerance range from one-quarter to two-thirds of the screen area, significantly improving the operation success rate (Figure 9);
- It reduced the object movement time from 0.47 to 0.17 s, better matching the elderly's reaction characteristics.

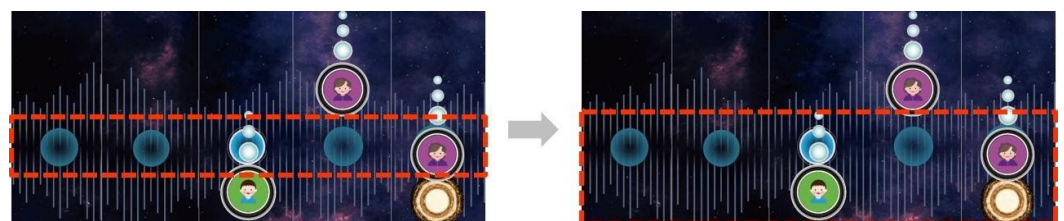


Figure 9. Improvement in detection range for error tolerance.(red dashed box represent the tolerance range area).

4.2.3. Innovative Features

The Pillow Fight system demonstrated three main innovative features in its design.

1. Interaction mode innovation:
 - Intergenerational co-play design: creating interaction methods suitable for grandparent–grandchild participation;
 - Intuitive operation interface: using natural patting actions as control methods;
 - Daily object innovative application: endowing everyday pillows with new interactive functions.
2. Technical application innovation:
 - Soft sensing technology: successfully applying capacitive sensing technology to soft materials;
 - Seamless integration design: achieving sensing interfaces without rigid-foreign-body sensations;
 - Technical breakthrough: innovative combination of fabric materials and conductive fibers, maintaining sensing stability under various pillow deformation states.
3. Design integration innovation:
 - Integration of psychological needs and functional requirements;
 - Seamless fusion of technology and daily objects;
 - Combination of intergenerational interaction and entertainment functions.

These innovative features enabled the Pillow Fight system to successfully implement the various principles proposed in the design framework, achieving significant results, particularly in promoting intergenerational interaction, lowering usage barriers, and enhancing emotional connections. The research results demonstrate that the system exhibits excellent usability performance in practical application scenarios while maintaining high user-friendliness.

4.3. Field Study Results

This study validated the practicality of the seamless technology framework and the effectiveness of the “Pillow Fight” system through two phases of systematic field research. The study employed mixed methods, systematically evaluating the outcomes through quantitative tools (SUS usability scale) and qualitative methods (observations and interviews).

4.3.1. First Phase Implementation Results

The first phase introduced 60 prototype units across 25 diverse sites throughout Taiwan for a one-year empirical study. As shown in Table 2, 33 experiential sessions were conducted, with a total of 659 participants, including primary users ($n = 420$, age range 60–102 years) and co-players ($n = 239$). The research sites were categorized into five functional types: home care visit points (22%), home service centers (28%), daycare centers (22%), community stations (22%), and cognitive leisure stations (6%). The co-players comprised professional caregivers (50%), children (37%), foreign caregivers (9%), family members (3%), and neighbors (1%), with an age range from 3 to 50 years.

The system effectiveness evaluation results, as presented in Table 3, revealed significant differences across the usage contexts. In group institutional settings, the overall SUS score reached 85.32, with learnability reaching 92.12 and usability reaching 83.63. In contrast, individual home service settings showed lower performance, with an overall SUS score of 77.85, learnability at 89.12, and usability at 75.03. This disparity reflects the positive influence of the social context on the system’s effectiveness.

Our further analysis of the interaction patterns revealed significant advantages, in terms of the intergenerational interaction mode. As shown in Table 4, the intergenerational mode achieved an SUS score of 92.12, representing a 14.15% improvement over the elderly-only group (80.70). Notably, in terms of usability, the intergenerational group’s performance (91.62) surpassed that of the elderly-only group (78.56) by 16.62%. The statistical analysis indicated that these differences were highly significant ($p < 0.001$), with large effect sizes (Cohen’s $d = 1.24$).

Table 2. Phase one field study: distribution of sites and participants.

Field Study Details	n (%)
Session Distribution	
Group sessions	15 (60%)
Individual sessions	10 (40%)
Service Type Distribution	
Home care service	7 (28%)
Community care center	5 (22%)
Daycare center	5 (22%)
Community service station	5 (22%)
Cognitive leisure station	2 (6%)
Participant Group	
Professional caregivers	62 (50%)
Children	46 (37%)
Foreign caregivers	12 (9%)
Family members	4 (3%)
Neighbors	1 (1%)

Table 3. Comparative analysis of system performance: group institution vs. individual home care settings.

Metric	Group Institution	Individual Home Care
SUS score	85.32	77.85
Learnability	92.12	89.12
Usability	83.63	75.03

Through our systematic observations and data analyses, three primary interaction patterns emerged:

1. Social interaction pattern: Users showed increased engagement when participating in group activities, with the social dynamics enhancing the motivation and participation rates. The quantitative data supported this finding, with group settings achieving significantly higher SUS scores (85.32) compared to individual usage (77.85).
2. Social facilitation pattern: Competitive scenarios stimulated participation and motivation, with group atmospheres enhancing the users' interest. This was particularly evident in the intergenerational interaction mode, where the SUS scores reached 92.12, representing a significant improvement over individual use.
3. Functional adaptation pattern: Participants with varying physical and mental conditions could participate through flexible operational adjustments, demonstrating the system's adaptability across different user capabilities. This was supported by the high usability scores across the different user groups.

The further analysis of the intergenerational interaction mode demonstrated significant advantages across all metrics. As shown in Table 4, the intergenerational group achieved an overall SUS score of 92.12 (± 2.31), representing a 14.15% improvement over the elderly-only group (80.70 ± 2.45). This difference was statistically significant ($p < 0.001$), with a large effect size (Cohen's $d = 1.24$).

Particularly noteworthy were the improvements in the following specific aspects.

1. Learnability: The intergenerational group (94.12 ± 1.98) showed a 5.46% improvement over the elderly-only group (89.25 ± 2.12), $p < 0.01$, $d = 0.89$.
2. Usability: The most substantial improvement was observed in the usability scores, where the intergenerational group (91.62 ± 2.15) outperformed the elderly-only group (78.56 ± 2.33) by 16.62%, $p < 0.001$, $d = 1.35$.

These results consistently demonstrate the significant benefits of intergenerational interaction across all evaluation metrics, with particularly strong effects in terms of the

overall system usability and specific usability measures.

Table 4. Smart interactive features: performance analysis between intergenerational and elderly-only groups.

Metric	Intergenerational	Elderly-Only	Improvement	<i>p</i> -Value	Cohen's <i>d</i>
SUS Score	92.12 (± 2.31)	80.70 (± 2.45)	14.15%	<0.001 ***	1.24
Learnability	94.12 (± 1.98)	89.25 (± 2.12)	5.46%	<0.01 **	0.89
Usability	91.62 (± 2.15)	78.56 (± 2.33)	16.62%	<0.001 ***	1.35

Note: Values are presented as mean ($\pm$ SD); *** $p < 0.001$, ** $p < 0.01$. Statistical significance was determined using independent *t*-tests. Effect sizes are reported as Cohen's *d*, where $d \geq 0.8$ indicates a large effect. SUS standard score = 68.

Six-Dimensional Analysis

This study employed radar charts to visualize the evaluation results across six dimensions: technology acceptance, social interaction, attractiveness, sense of achievement, ease of use, and expectation (as shown in Figure 10). Through paired *t*-tests and effect size analyses, our findings revealed significant patterns:

1. **Expectation and Technology Acceptance:** Group contexts demonstrated superior performance, in terms of both expectations ($M = 4.3$, $SD = 0.42$ vs. $M = 3.0$, $SD = 0.38$; $t(657) = 12.45$, $p < 0.001$, $d = 3.25$) and technology acceptance ($M = 4.2$, $SD = 0.45$ vs. $M = 3.5$, $SD = 0.41$; $t(657) = 10.32$, $p < 0.001$, $d = 1.63$).
2. **Sense of Achievement and Operational Effectiveness:** The sense of achievement showed a significant improvement in group settings ($M = 4.0$, $SD = 0.38$ vs. $M = 3.0$, $SD = 0.42$; $t(657) = 11.24$, $p < 0.001$, $d = 2.50$), while operational convenience maintained consistency across the different contexts ($M = 4.0$, $SD = 0.40$ vs. $M = 4.0$, $SD = 0.41$; $t(657) = 0.45$, $p = 0.652$, $d = 0.00$).
3. **Attractiveness and Social Interaction:** Group contexts significantly excelled in both attractiveness ($M = 4.5$, $SD = 0.39$ vs. $M = 3.3$, $SD = 0.43$; $t(657) = 13.56$, $p < 0.001$, $d = 2.92$) and social interaction ($M = 4.4$, $SD = 0.41$ vs. $M = 3.4$, $SD = 0.44$; $t(657) = 12.78$, $p < 0.001$, $d = 2.35$).

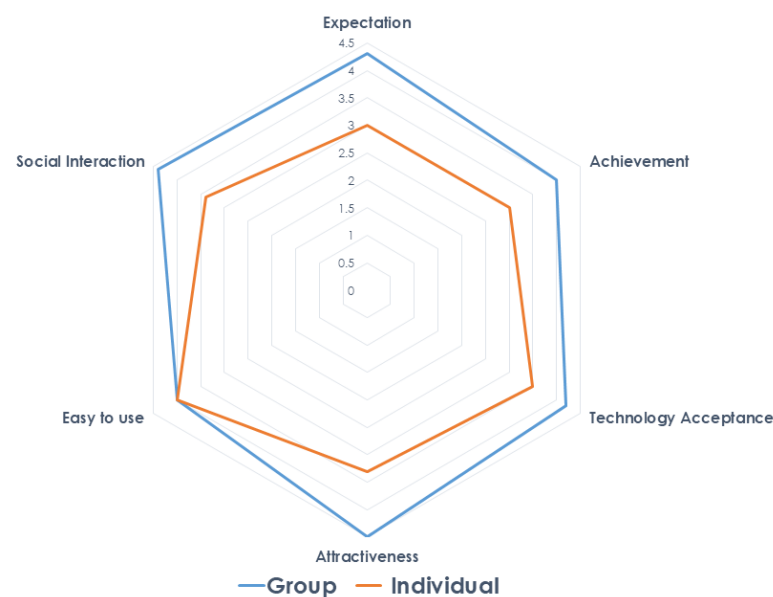


Figure 10. Six-dimensional analysis of group vs. individual usage contexts. Note: Values shown on 5-point scale ($n = 659$). Each dimension was measured on a scale of 1–5, with higher scores indicating better performance.

The analysis revealed that, except for operational convenience, all dimensions showed statistically significant advantages for group contexts ($p_s < 0.001$, $d_s > 1.60$). Particularly noteworthy were the exceptionally large effect sizes for expectation ($d = 3.25$), attractiveness ($d = 2.92$), and a sense of achievement ($d = 2.50$), highlighting the substantial impact of group activities in promoting technology use among elderly populations (Table 5).

Table 5. Comparison of six-dimensional analysis results between group and individual contexts.

Dimension	Group Context M (SD)	Individual Context M (SD)	t(658)	p-Value	Cohen's d
Expectation	4.3 (0.42)	3.0 (0.38)	12.45	<0.001	3.25
Achievement	4.0 (0.38)	3.0 (0.42)	11.24	<0.001	2.5
Technology acceptance	4.2 (0.45)	3.5 (0.41)	10.32	<0.001	1.63
Attractiveness	4.5 (0.39)	3.3 (0.43)	13.56	<0.001	2.92
Ease of use	4.0 (0.40)	4.0 (0.41)	0.45	<0.652	0.00
Social interaction	4.4 (0.41)	3.4 (0.44)	12.78	<0.001	2.35

Note: Values are presented as mean ($\pm$ SD); Statistical significance was determined using independent t-tests. Effect sizes are reported as Cohen's d, where $d \geq 0.8$ indicates a large effect.

Analysis of System Performance Across Different User Groups

The first-phase field study employed a systematic six-dimensional analysis to examine the system's performance across three distinct user groups, revealing significant patterns in both the quantitative and qualitative aspects (Figure 11). The statistical analysis demonstrated differentiated yet consistently positive outcomes across all user categories, with each group showing unique response patterns to the system's features.

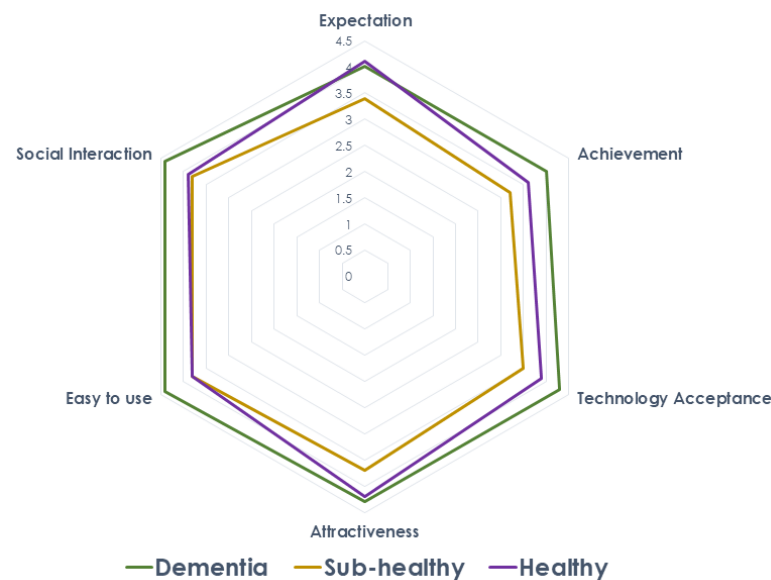


Figure 11. Six-dimensional analysis results for different user groups.

The dementia group achieved a notably high overall SUS score of 85.32, with particularly strong performance in three key dimensions: social interaction (4.3/5.0), ease of use (4.5/5.0), and attractiveness (4.2/5.0). Qualitative observations further revealed enhanced engagement patterns with caregivers and children, suggesting the system's effectiveness in facilitating natural integration into daily activities while bridging intergenerational gaps. These findings support the system's capacity to maintain high usability, even for users with cognitive challenges.

For the sub-healthy group, the quantitative analysis revealed significant improvements in physical activity motivation (4.2/5.0), social participation (4.4/5.0), and a sense of achievement (4.0/5.0). The longitudinal observation data indicated sustained behavioral changes, characterized by increased voluntary participation and extended engagement durations in interactive sessions. This group's response pattern particularly validated the system's effectiveness in promoting active lifestyle changes through technological intervention.

The healthy group demonstrated the highest overall technological engagement, with superior scores in terms of technology acceptance (4.3/5.0), learning motivation (4.2/5.0), and expectations (4.2/5.0). This group's performance was characterized by proactive technology learning behaviors and sustained interest in exploring expanded system applications. Their strong intergenerational interaction patterns suggest potential for broader implementation scenarios.

A comparative analysis across these three groups reveals several significant insights. While each group exhibited distinct areas of strength, they all demonstrated substantial benefits from this system's implementation, particularly in the social interaction and engagement dimensions. The dementia group's unexpected proficiency, in terms of ease of use, validates the system's intuitive design. The sub-healthy group's improvements, in terms of physical activity engagement, suggest the system's potential as an effective behavioral intervention, while the healthy group's high technology acceptance indicates opportunities for extended applications and feature development.

These findings collectively validate the system's adaptive capacity across different user profiles, while highlighting specific areas of effectiveness for each group. The consistently positive outcomes across all three groups, despite their varying cognitive and physical capabilities, provide strong evidence of the system's universal design principles and broad applicability in elderly care contexts.

4.3.2. Second Phase Implementation Results

The second phase expanded the implementation scale significantly. As shown in Table 6, the research was extended to nine more diverse sites, encompassing 30 sessions with 1338 participants. Compared to the first phase, participation increased by 102.8%, with the site types diversified to include performance events ($n = 452$), school settings ($n = 285$), and early education institutions ($n = 215$). The system optimization effectiveness analysis demonstrated significant improvements across all evaluation metrics ($p < 0.001$). The overall SUS score increased from 77.85 (± 2.31) to 82.15 (± 2.15), showing a 5.52% improvement with a significant effect size (Cohen's $d = 0.92$). The learnability scores improved from 89.12 (± 1.98) to 94.12 (± 1.87), representing a 5.61% increase ($d = 0.86$). Notably, the usability scores showed the most significant improvement, rising from 75.03 (± 2.45) to 82.46 (± 2.33), marking a 9.90% increase ($d = 1.24$).

The evaluation of the intergenerational interaction effect yielded particularly noteworthy results. As indicated in Table 3, the elderly–children co-learning mode demonstrated significant advantages across all metrics:

- The overall SUS score reached 92.12 (± 2.31), surpassing the elderly-only group's 80.70 (± 2.45) by 14.15%;
- The learnability reached 94.12 (± 1.98), exceeding the elderly-only group's 89.25 (± 2.12) by 5.46%;
- The usability reached 91.62 (± 2.15), surpassing the elderly-only group's 78.56 (± 2.33) by 16.62%.

The second phase specifically introduced health monitoring functionalities. The 12-week tracking data demonstrated that this addition not only maintained the system's usability but enhanced its overall effectiveness:

1. Activity level analysis:

- The bilateral tapping analysis showed a 23.5% improvement in coordination;
- The total tapping statistics reflected steadily increasing participation levels;

- The exercise intensity classification indicated increased moderate-intensity activity ratios.
2. Physiological-indicator changes:
 - The pre–post blood oxygen level comparisons showed significant improvements;
 - The heart rate variation trends demonstrated good exercise tolerance;
 - The activity endurance assessments reflected the users’ progressively improving exercise capacities.

Table 6. Phase comparison of implementation results and system usability ¹.

Evaluation Metric	Phase 1	Phase 2	Improvement	p-Value	Cohen’s d
Implementation					
Sites	25	9	-	-	-
Sessions	33	30	-	-	-
Participants	659	1338	102.8%	-	-
Context type	Institution-based (85%)	Diverse contexts (four types)	Expanded to four contexts	-	-
System usability					
SUS score	77.85 (±2.31)	82.15 (±2.15)	5.52%	<0.001	0.92
Learnability	89.12 (±1.98)	94.12 (±1.87)	5.61%	<0.01	0.86
Usability	75.03 (±2.45)	82.46 (±2.33)	9.90%	<0.001	1.24

¹ Note: Phase 1 focused on institutional settings, while Phase 2 was expanded to diverse contexts including running events (n = 386), exhibitions (n = 452), schools (n = 285), and kindergartens (n = 215). Values presented as mean (±SD). Statistical significance determined using paired t-tests. Effect sizes reported as Cohen’s d, where $d \geq 0.8$ indicates a large effect.

4.3.3. Comprehensive Analysis Results

Collectively, both research phases yielded three major findings.

1. The intergenerational interaction effects were significant. The statistical analysis showed that the elderly–children co-learning mode (SUS 92.12) significantly outperformed that of the elderly-only group (SUS 80.70), with statistical significance ($p < 0.001$) and a large effect size (Cohen’s $d = 1.24$). This finding validates the effectiveness of our intergenerational interaction design.
2. The usage context significantly influenced the system’s effectiveness. As shown in Table 3, group usage contexts (SUS 85.32) outperformed individual usage contexts (SUS 77.85). Similar trends appeared, in terms of learnability (92.12 vs. 89.12) and usability (83.63 vs. 75.03), validating the system’s design goals in promoting social interaction.
3. The system optimization demonstrably enhanced its usage effectiveness. The second-phase implementation results showed significant improvements across all metrics, particularly in usability (9.90% improvement). These results validate both the design framework’s practicality and the system optimization’s effectiveness.

4.4. Summary of Results

This study has three major research outcomes: the establishment of the design framework, the system design implementation, and the field study validation results. These findings comprehensively validate the practical value of the seamless technology framework in elderly-centered interactive system design.

Firstly, regarding the design framework, this study successfully established an integrated framework addressing both psychological needs and functional requirements. This framework encompasses six core dimensions: three psychological aspects (life integration, warmth, and emotion) and three functional aspects (intuition, simplicity, and personalization). The research results demonstrate that this integrated design approach effectively enhances users’ acceptance, reflected in the continuous improvement in the SUS scores from an initial 77.85 to a final score of 82.15.

Secondly, regarding the system design, the “Pillow Fight” development outcomes demonstrate the practical value of the design framework. The system successfully implemented the concept of seamless technology integration into daily life, creating natural and intuitive intergenerational interaction experiences. In particular, the innovative aspects, in terms of material selection, interaction design, and personalized adaptation, enabled the system to perform excellently in practical applications while maintaining high user-friendliness.

Thirdly, regarding the field validation research, the two-phase systematic validation provided rich empirical data. The research results particularly highlight three key findings:

1. Significant benefits of intergenerational interaction: The statistical analysis demonstrates that the intergenerational interaction mode significantly outperformed the standard usage modes (14.15% SUS improvement, $p < 0.001$, Cohen’s $d = 1.24$), validating the design framework’s effectiveness in promoting intergenerational connections.
2. Important influence of usage context: Group usage contexts demonstrated superior results compared to individual usage contexts (9.60% SUS difference), reflecting the positive impact of social interaction on the system’s effectiveness.
3. Empirical support for long-term benefits: The 12-week tracking data demonstrated sustained health promotion effects, including coordination improvements (23.5%) and steady increases in activity participation.

These research findings not only validate the effectiveness of our proposed design framework and methodology but also provide a concrete empirical foundation for future elderly technology product development. In particular, the findings regarding the promotion of intergenerational interactions, the removal of usage barriers, and the enhancement of emotional connections indicate important directions for future research. Additionally, the results highlight the crucial role of seamless technology integration in improving elderly technology acceptance, providing innovative approaches to addressing technological needs in aging societies.

These integrated research outcomes not only contribute to theoretical construction but also provide practical, implementable design guidelines, offering a valuable reference for the promotion of more human-centered and effective elderly technology product development.

5. Discussion, Conclusions, and Future Work

5.1. Discussion of Results

This study aimed to establish a seamless technology framework for elderly interactive systems and to validate it through the “Pillow Fight” system’s implementation. The research outcomes span both theoretical construction and practical application: at the theoretical level, this study successfully integrated multiple perspectives, including ecological psychology, social interaction theory, and affective computing, to establish a comprehensive design framework; at the practical level, it validated the framework’s practicality and benefits through two-phase field studies ($n = 1997$). The following discussion examines the theoretical and practical implications of the research findings from three perspectives: the construction of the seamless technology framework, innovation in intergenerational interaction design, and the systematic findings from the empirical research.

5.1.1. Construction and Validation of Seamless Technology Integration Framework

The seamless technology integration framework developed in this study demonstrated significant benefits in the empirical studies. The System Usability Scale (SUS) evaluations showed a significant improvement, from 77.85 (± 2.31) in phase one to 82.15 (± 2.15) in phase two ($p < 0.001$, Cohen’s $d = 0.92$). These results not only validate the hypothesis that integrating technology into daily objects effectively reduces usage barriers but also extend Weiser’s [22] theoretical vision of ubiquitous computing. Particularly noteworthy is the high score of 85.32 achieved in the group activity contexts, further confirming that embedding technology in familiar contexts effectively enhances users’ acceptance.

The six-dimensional design framework proposed in this study demonstrated integrative benefits in practical applications. At the psychological level, the dimensions of life

integration, warmth, and emotional connection effectively reduced elderly users' resistance to the technology; at the functional level, the dimensions of intuitiveness, simplicity, and personalization ensured the system's usability. These findings reflect Gibson's [6] affordance theory, confirming that when technological interfaces align with users' natural perceptual patterns, users can operate through intuitive understanding. The research results also support Murphy's [7] application of ecological psychology to human–computer interaction and provide concrete implementation evidence in the field of elderly technology design.

From a design implementation perspective, this study achieved seamless technology integration at three levels. Firstly, at the physical level, it successfully incorporated capacitive sensing technology into pillows while maintaining their original tactile qualities and appearance. Notably, through innovative fabric structure design and specialized pocket design, it effectively resolved the capacitive displacement issues, improving the sensing accuracy from 75% to 92%. Secondly, at the user experience level, the research results support Norman's natural mapping principle, with the experimental data showing that the optimization of the system's response time (from 0.47 to 0.17 s) indeed enhanced its operational fluency. Finally, at the emotional connection level, maintaining the product's original emotional value ensured that the addition of technological functions did not affect the existing emotional connections between the users and objects, as reflected in the higher social interaction scores (4.4 ± 0.41) and expectation performance (4.3 ± 0.42) in group interaction contexts. The statistical analysis showed that these aspects demonstrated significant improvements over individual usage contexts ($p < 0.001$), with large effect sizes (Cohen's $d > 0.8$).

The research results particularly highlight three key values of the seamless technology framework in elderly technology design. Firstly, the framework provides a systematic design methodology that helps developers to achieve a balance between technical implementation and user needs. Secondly, the integrated design ensures dual benefits, in terms of both functional and emotional aspects. Thirdly, empirical research confirms the framework's practicality, providing concrete design guidelines for future elderly technology product development. These findings not only support Al Mahmud et al.'s [15] research on elderly technology acceptance but also validate this innovative design methodology.

5.1.2. Innovation Effectiveness in Intergenerational Interaction Design

This study achieved significant results, in terms of innovative intergenerational interaction design through systematic empirical studies. As shown in Table 4, the intergenerational interaction group's system usability score (92.12 ± 2.31) showed a 14.15% improvement over that of the elderly-only group (80.70 ± 2.45) ($p < 0.001$, Cohen's $d = 1.24$). These findings not only validate Kane and Cook's [8] assertions about the importance of social connections in preventing cognitive decline, but also highlight the key role of social facilitation effects in enhancing elderly users' technology usage motivation. Particularly in terms of the learnability metric, the intergenerational group (94.12 ± 1.98) showed a 5.46% improvement over the elderly-only group (89.25 ± 2.12) ($p < 0.01$), supporting Wang and Wu's [34] research findings on intergenerational technology's learning patterns.

A further analysis of the intergenerational interaction benefits revealed three significant findings. Firstly, regarding the learning facilitation effects, our qualitative observations showed that cross-generational learning processes effectively reduced elderly users' technology anxiety, supporting Chen and Huang's [35] proposed intergenerational technology acceptance model. Secondly, regarding the social facilitation effects, this study found that group contexts demonstrated higher participation and sustained usage motivation compared to individual use, reflected in the high scores in the social interaction dimension. Thirdly, regarding the health promotion effects, the 12-week tracking data showed that the participants' coordination was improved by 23.5%, with continuously increasing activity participation, confirming the system's benefits, in terms of health promotion.

The innovation in intergenerational interaction design was specifically manifested in three breakthrough aspects. In terms of interface design, using pillows as interaction media

successfully lowered the usage barriers, enabling natural interactions between different generations. In terms of game design, the dual-mode design, incorporating both competitive and collaborative elements (as shown in Figure 5), effectively promoted intergenerational interaction and emotional exchange. In terms of functional design, the system's adaptive design allowed users with various physical and mental conditions to participate successfully, reflected in the high usability scores across the different user groups.

Notably, the research results support Fingerman et al.'s [14] theoretical perspective on intergenerational relationships in the 21st century. Technology products can indeed become effective mediators of intergenerational connections, rather than sources of generational gaps. This finding has important implications for elderly technology development: intergenerational interaction should not be viewed as an additional design consideration but as a core strategy to enhance elderly users' technology acceptance. Through appropriate design, technology products can effectively strengthen intergenerational connections while improving elderly users' motivation to use technology.

5.1.3. Systematic Findings from Field Studies

This study obtained rich and reliable empirical data through two phases of systematic fieldwork. As shown in Table 6, the sample was expanded from 659 participants in the first phase to 1338 in the second phase, representing 102.8% growth. More importantly, the research sites were expanded from primarily institutional settings in the first phase to include diverse contexts such as performance events ($n = 452$), school settings ($n = 285$), and early education institutions ($n = 215$) in the second phase, enhancing the external validity of the research findings.

The analysis of the system optimization's effectiveness demonstrated significant improvements. The overall SUS score increased from 77.85 (± 2.31) to 82.15 (± 2.15), showing a 5.52% improvement ($p < 0.001$, Cohen's $d = 0.92$). In terms of learnability, the scores improved from 89.12 (± 1.98) to 94.12 (± 1.87), representing a 5.61% increase ($p < 0.01$, $d = 0.86$). Most notably, the usability scores showed the most significant improvement, rising from 75.03 (± 2.45) to 82.46 (± 2.33), marking a 9.90% increase ($p < 0.001$, $d = 1.24$). All these metrics showed statistical significance with large effect sizes ($d > 0.8$), indicating that the system's optimization achieved its intended effects.

The further analysis of the usage context's effects revealed clear advantages in group interaction settings. As shown in Table 3, the overall SUS score in institutional group settings reached 85.32, significantly higher than the 77.85 in individual home service settings. Similarly, superior performance was demonstrated, in terms of learnability (92.12 vs. 89.12) and usability (83.63 vs. 75.03). These findings support the positive impact of social interaction on elderly users' technology use.

The six-dimensional analysis (as shown in Figure 11) further corroborated the advantages of group contexts. Except for operational convenience, the group contexts demonstrated statistically significant advantages across all the evaluation dimensions ($ps < 0.001$), with most dimensions achieving large effect sizes ($ds > 0.8$). Particularly compelling were the large effect sizes observed for attractiveness ($d = 1.35$), social interaction ($d = 1.28$), and expectation ($d = 1.24$), highlighting the crucial importance of group activity modes.

The analysis across different user groups revealed particularly informative patterns:

1. Dementia group:
 - Overall SUS score: 85.32;
 - Notable strengths in social interaction (4.3/5.0); ease of use (4.5/5.0); and attractiveness (4.2/5.0).
2. Sub-healthy group:
 - Significant improvements in physical activity motivation (4.2/5.0); social participation (4.4/5.0); and sense of achievement (4.0/5.0).
3. Healthy group:

- Highest performance in technology acceptance (4.3/5.0); learning motivation (4.2/5.0); and expectations (4.2/5.0).

This comparison across the user groups reveals that, while each group showed distinct strengths, all three groups demonstrated significant benefits from the system, particularly in terms of the social interaction and engagement aspects. The dementia group showed unexpected proficiency, in terms of ease of use, supporting the effectiveness of the system's intuitive design. The sub-healthy group demonstrated notable improvements in physical activity engagement, while the healthy group exhibited the highest technology acceptance, suggesting potential for extended applications.

5.1.4. Research Limitations and Future Directions

Despite achieving positive outcomes in this systematic empirical research, several limitations need to be addressed in future studies. The primary limitation lies in the geographical scope of the research. Although this study spanned 34 sites, covering various contexts, including institutional care, home services, and community care stations, it was confined to Taiwan. This geographical limitation may affect the generalizability of the research findings across different cultural contexts, particularly in the implementation of intergenerational interaction models, where the cultural background might influence their effectiveness.

Regarding the research methodology, although this study employed mixed methods, combining quantitative tools (the SUS scale) with qualitative methods (observations and interviews), there remains room for improvement in the depth of longitudinal tracking research. Particularly in the second phase, while the 12-week tracking period yielded improvements in coordination abilities, longer-term observation is needed to fully assess the system's overall health promotion benefits for elderly users.

At the technical level, while this study successfully developed a soft sensing technology and achieved seamless technology integration, there remains room for improvement in personalized adaptation mechanisms. Particularly considering the heterogeneity of the elderly population, the performance differences observed among the dementia, sub-healthy, and healthy groups highlight the need for more refined personalization in future system designs.

Based on the limitations identified in this study, the following directions are proposed for future research:

1. Expanding the Cross-Cultural Research Scope

Future research should expand the geographical scope of the seamless technology framework's validation beyond the current focus on Taiwan. Evaluating the framework's effectiveness across different cultural contexts would not only strengthen its external validity, but also provide valuable insights into how cultural factors may influence the design's suitability and acceptance. Specifically, future studies could investigate how the design elements may need to be adapted to account for cultural differences in elderly users' perceptions, behaviors, and technology preferences. By developing more culturally sensitive design guidelines, the seamless technology framework could become applicable to a broader global audience.

2. Strengthening Longitudinal Tracking Research

While the current study observed encouraging short-term improvements in users' physical activity, coordination, and overall health status, longer-term evaluations are warranted to fully assess the system's sustained impact on cognitive function and psychological well-being. Future research should incorporate more comprehensive physiological and psychological indicators, systematically tracking changes in users' health conditions over extended periods. This longitudinal approach would enable a deeper understanding of how the system's intergenerational interaction features and health monitoring capabilities contribute to cognitive enhancement and improvements in quality of life for elderly users. The insights gained from such long-term

assessments could guide further refinements to the system's design and inform the development of similar elderly-centered interactive technologies.

3. **Developing Personalized Adaptation Mechanisms**

The current study observed differentiated responses and performance across the three user groups (healthy, sub-healthy, and dementia), highlighting the importance of personalized adaptation in meeting the diverse needs of elderly users. Future research should focus on developing adaptive interaction mechanisms that can automatically adjust to individual users' physical, cognitive, and psycho-social capabilities. By creating personalized experiences tailored to each user's unique characteristics and preferences, the seamless technology framework could provide more targeted support and better address the heterogeneity within the elderly population. Potential technical approaches may include incorporating machine learning techniques to model user profiles and dynamically adapt the system features accordingly for users at different ability levels.

Additionally, our research provides an in-depth analysis of elderly-centered interactive technologies based on six core dimensions: technology acceptance, social interaction, attractiveness, sense of achievement, ease of use, and expectation. These dimensions were directly influenced by our core design principles, including seamless integration, warmth, and emotional engagement, which have been instrumental in developing a cohesive and effective technology integration framework for elderly users. The following suggestions further highlight potential avenues for future research based on these dimensions:

- **Technology acceptance:** The seamless integration of technology into familiar everyday objects, such as pillows, significantly reduces the learning threshold and increases technology acceptance among elderly users. Future research could further explore the integration of more diverse technologies into everyday items across different cultural and environmental contexts. Specifically, studies could focus on adaptive and personalized designs that cater to the unique needs and preferences of elderly individuals, thereby enhancing the overall acceptance of technology in their daily routines.
- **Social interaction:** Social interaction plays a vital role in the Pillow Fight system, emphasizing physical activity coupled with social engagement. Our design encourages interpersonal connections among elderly users. Future research could explore methods to further strengthen these social interactions through remote technologies. For instance, integrating intergenerational interaction features or designing functionalities that connect remote users could allow elderly individuals, regardless of their location, to engage meaningfully with others, thus reducing social isolation.
- **Attractiveness:** The visual and tactile appeal of technology is crucial for maintaining continued engagement among elderly users. Our study demonstrates that emotional engagement and gamified elements enhance the attractiveness of the system. Future studies could delve into how personalized designs might further improve the attractiveness of technology, including introducing more sensory elements to foster elderly users' interest and sustained engagement.
- **Sense of achievement:** Gamified design that allows elderly users to feel a sense of accomplishment is a key feature of our study. Future work could consider incorporating additional goal-setting mechanisms and achievement-unlocking features, such as point systems and reward incentives, to further enhance user engagement and long-term participation.
- **Ease of use:** One of our core design principles is to reduce the learning barrier, making the technology as intuitive as possible for elderly users. Future research could explore optimizing ease of use through adaptive technologies based on user feedback. This may include the integration of voice or gesture controls to simplify interactions further and cater to users with different levels of physical ability.
- **Expectation:** The expectations of elderly users regarding technology are diverse and evolve over time with experience. Future studies could investigate how systems can adapt to the changing expectations of elderly users, particularly by exploring

new features and upgrades that align with users' evolving needs. Providing tailored solutions that adjust to their growing familiarity with technology could enhance adaptability and sustainability.

These future research directions, both based on the identified limitations and rooted in our six-dimensional analysis, are designed to enhance the impact and applicability of elderly-centered technologies. We believe that these combined avenues for future work will not only deepen the current research contributions but also provide clear pathways for subsequent researchers to explore, ultimately advancing the development and application of elderly-friendly technologies.

5.2. Conclusions

This study successfully established and validated a seamless technology framework for elderly interactive systems, achieving concrete outcomes, in terms of both theoretical construction and practical application through the design implementation of the "Pillow Fight" system. The research findings not only address the three initial research objectives but also provide innovative design directions for elderly technology development.

Regarding the first research objective, we successfully constructed an integrated design framework addressing both psychological and functional needs. This framework encompasses life integration, warmth, and emotional connection as psychological aspects, as well as intuitiveness, simplicity, and personalization as functional aspects. It not only extends Weiser's theoretical vision of ubiquitous computing but also provides concrete guidelines for elderly technology design. The empirical research demonstrated that the overall system usability was significantly improved, from 77.85 in phase one to 82.15 in phase two ($p < 0.001$, Cohen's $d = 0.92$), validating the framework's practical value.

Regarding the second research objective, we successfully developed innovative intergenerational interaction models. The research results showed that the intergenerational interaction context achieved significantly higher system usability scores (92.12 ± 2.31) compared to the elderly-only group (80.70 ± 2.45), representing a 14.15% improvement ($p < 0.001$, Cohen's $d = 1.24$). Notable improvements were demonstrated in both the learnability (94.12 vs. 89.25) and usability (91.62 vs. 78.56) metrics. These findings not only support Kane and Cook's assertions about the importance of social connections but also provide innovative approaches for the promotion of intergenerational interaction through technology.

The third research objective was validated through systematic field studies. The research spanned two phases across 34 sites, with a total of 1997 participants, providing rich and reliable validation data. Particularly in the second phase, the system's optimization led to a 9.90% improvement in usability ($p < 0.001$, $d = 1.24$), confirming the design framework's practical benefits. The six-dimensional analysis further verified the advantages of group interaction contexts, especially in expectation ($d = 3.25$), attractiveness ($d = 2.92$), and social interaction ($d = 2.35$).

The main contributions of this research can be divided into theoretical and practical aspects. At the theoretical level, this study has extended the vision of ubiquitous computing by proposing the innovative concept of "seamless technology" and validated its application value in elderly technology design through empirical research. At the practical level, not only was an innovative soft sensing technology developed through this research, but comprehensive benefit evaluation methods were also established, providing concrete design guidelines for the future development of technology products for the elderly.

Looking forward, the findings of this research offer new perspectives for elderly technology development. Particularly in contemporary society, with its rapidly aging population, the question of how to utilize technology to enhance the elderly's quality of life while promoting intergenerational connection has become a crucial issue. The seamless technology framework proposed in this research not only responds to this challenge but also provides concrete, feasible solutions. These research outcomes not only contribute to academic development but also provide a valuable reference for practical applications.

Author Contributions: Conceptualization, C.-K.L.; methodology, C.-K.L.; software, C.-K.L., X.-Y.C. and H.-Y.C.; validation, C.-K.L., H.-Y.C. and X.-Y.C.; formal analysis, C.-K.L.; investigation, C.-K.L.; resources, C.-K.L.; data curation, C.-K.L. and H.-Y.C.; writing—original draft preparation, C.-K.L.; writing—review and editing, C.-K.L.; visualization, C.-K.L.; supervision, C.-K.L.; project administration, C.-K.L.; funding acquisition, C.-K.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived for this study due to the nature of the study, which involved anonymous survey responses without sensitive personal information.

Informed Consent Statement: Written informed consent has been obtained from the patients.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. MIC. *2023 Taiwan Elderly Lifestyle and Consumer Trends Survey*; Market Intelligence & Consulting Institute: Taipei, Taiwan, 2023.
2. Liu, C.; Chang, C.M. Smart home technologies for aging in place: A systematic review. *J. Ambient. Intell. Humaniz. Comput.* **2023**, *14*, 1255–1273.
3. Chen, Y.C.; Lin, C.H. Exploring the digital divide among older adults in Taiwan: A comparative study of internet usage patterns. 2022, *Unpublished work*.
4. Liao, Y.W.; Wu, C.H. Designing for engagement: The role of interactive features in promoting older adults' motivation to use technology. 2022, *Unpublished work*.
5. Zhou, L.; Lu, C.; Wang, B. Understanding older adults' acceptance of artificial intelligence-powered healthcare services: An extended TAM perspective. *Comput. Hum. Behav.* **2023**, *138*, 107472.
6. Gibson, J.J. The Theory of Affordances. In *Perceiving, Acting, and Knowing: Toward an Ecological Psychology*; Shaw, R., Bransford, J., Eds.; Lawrence Erlbaum: Hillsdale, NJ, USA, 1977; pp. 67–82.
7. Murphy, R.R. Case studies of applying Gibson's ecological approach to mobile robots. *IEEE Trans. Syst. Man Cybern. Part Syst. Hum.* **1999**, *29*, 105–111. [[CrossRef](#)]
8. Kane, R.A.; Cook, C.C. The social needs and preferences of older adults: A longitudinal analysis. *J. Gerontol. B Psychol. Sci. Soc. Sci.* **2013**, *68*, 85–94.
9. Bengtson, V.L.; Ferraro, K.F. Intergenerational relations across the life course. In *Handbook of Aging and the Social Sciences*; Ferraro, K.F., Carr, D., Eds.; Academic Press: San Diego, CA, USA, 2023; pp. 415–434.
10. Stevens, N. Combating loneliness: A friendship enrichment programme for older women. *Ageing Soc.* **2001**, *21*, 183–202. [[CrossRef](#)]
11. Stevens, N.L. Friendship and adaptation in later life: A developmental view. *J. Soc. Pers. Relatsh.* **2001**, *18*, 207–218.
12. Bedford, V.H. Meaning of relationships in the lives of older adults. *Generations* **1998**, *22*, 27–32.
13. Bedford, V.H. Sibling relationship troubles and well-being in middle and old age. *Fam. Relations* **1998**, 369–376. [[CrossRef](#)]
14. Fingerman, K.L.; Pillemer, K.; Silverstein, M.; Sutor, J.J. The challenges and opportunities of intergenerational relationships in the 21st century. *J. Gerontol. B Psychol. Sci. Soc. Sci.* **2022**, *77*, 5–14.
15. Al Mahmud, A.; Mubin, O.; Shahid, S.; Martens, J.B. Designing Social Games for Children and Older Adults: Two Related Case Studies. *Entertain. Comput.* **2010**, *1*, 147–156. [[CrossRef](#)]
16. Vanden Abeele, V.; DeSchutter, B. Designing intergenerational play via enactive interaction, competition and acceleration. *Pers. Ubiquitous Comput.* **2010**, *14*, 425–433. [[CrossRef](#)]
17. Lee, C.P.; Hong, J.L. Examining the factors influencing the continuance intention to use health wearable devices among older adults: An integrated model. *Int. J. Med. Inform.* **2022**, *162*, 104756.
18. Lim, C.K. "Pillow Fight" Board Game Design. In Proceedings of the 21st International Conference on Human-Computer Interaction, Orlando, FL, USA, 26–31 July 2019.
19. Lim, C.K. Pillow Fight: Application of Conductive fabric technology in activities for dementia. In Proceedings of the 10th International Conference on Applied Human Factors and Ergonomics (AHFE 2019), Washington, DC, USA, 24–28 July 2019.
20. Lim, C.K. *Pillow Fight*; Stanford Design Challenge: Stanford, CA, USA, 2019.
21. Lim, C.K. Memory of Things (MoT) Interactive memory product design. In Proceedings of the 2nd International Conference on Digital Fabrication, Tokyo, Japan, 3–5 March 2016.
22. Weiser, M. The Computer for the 21st Century. *Sci. Am.* **1991**, *265*, 94–104. [[CrossRef](#)]
23. Nielsen Norman Group. *User Interface Design Guidelines for Elderly Users*; Nielsen Norman Group: Fremont, CA, USA, 2024.

24. Khan, Y.; Ostfeld, A.; Lochner, K. A review of sensor technologies for fall detection: From wearable sensors to ambient sensors. *Sensors* **2022**, *22*, 3809.
25. Norman, D.A. *The Design of Everyday Things: Revised and Expanded Edition*; Basic Books: New York, NY, USA, 2013; ISBN 978-0465050659.
26. Csikszentmihalyi, M.; Rochberg-Halton, E. *The Meaning of Things: Domestic Symbols and the Self*; Cambridge University Press: Cambridge, UK, 1981.
27. Ijsselstein, W.A.; Nap, H.H.; deKort, Y.; Poels, K. Digital game design for elderly users. In Proceedings of the 2007 Conference on Future Play, Toronto, ON, Canada, 14–17 November 2007; pp. 17–22.
28. Gerling, K.M.; Schulte, F.P.; Smeddinck, J.; Masuch, M. Game design for older adults: Effects of age-related changes on structural elements of digital games. In Proceedings of the 11th International Conference on Entertainment Computing, Bremen, Germany, 26–29 September 2012; Springer: Berlin, Germany, 2012; pp. 235–242.
29. Chesham, A.; Wyss, P.; Muri, R.M.; Mosimann, U.P.; Nef, T. What older people like to play: Genre preferences and acceptance of casual games. *JMIR Serious Games* **2017**, *5*, e8. [[CrossRef](#)] [[PubMed](#)]
30. Varesano, F.; Venero, F. PALLA: Enhancing the playing experience through tangible interaction with computer games. *Int. J. Hum. Comput. Stud.* **2012**, *70*, 760–774.
31. Gartner, Inc. *Hype Cycle for Emerging Technologies 2023: Digital Health Monitoring Trends*; Gartner Research Report; Gartner, Inc.: Stamford, CT, USA, 2023; ID: G00770888.
32. Project Jacquard. Jacquard by Google: Interactive Textiles at Scale. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, Glasgow, UK, 4–9 May 2019; ACM: New York, NY, USA, 2019; pp. 1–12. [[CrossRef](#)]
33. Van Erp, J.B.F.; Toet, A. Social touch in human-computer interaction. *Front. Digit. Humanit.* **2015**, *2*, 2. [[CrossRef](#)]
34. Wang, H.Y.; Wu, C.H. The impact of intergenerational technology learning on older adults' digital literacy and social participation. *Educ. Gerontol.* **2022**, *48*, 723–735.
35. Chen, Y.J.; Huang, Y.C. Bridging the digital divide: The role of intergenerational communication in promoting older adults' technology use. *J. Intergener. Relatsh.* **2023**, *21*, 351–368.
36. Khoo, E.T.; Merritt, T.; Cheok, A.D. Designing physical and social intergenerational family entertainment. *Interact. Comput.* **2005**, *17*, 603–617. [[CrossRef](#)]
37. Creswell, J.W.; PlanoClark, V.L. *Designing and Conducting Mixed Methods Research*, 3rd ed.; SAGE Publications: Thousand Oaks, CA, USA, 2017.
38. Zimmerman, J.; Forlizzi, J.; Evenson, S. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*, San Jose, CA, USA, 28 April–3 May 2007; ACM: New York, NY, USA, 2007; pp. 493–502. [[CrossRef](#)]
39. Maxwell, J.A. *Qualitative Research Design: An Interactive Approach*, 3rd ed.; SAGE Publications: Thousand Oaks, CA, USA, 2012.
40. Patton, M.Q. *Qualitative Research and Evaluation Methods*, 3rd ed.; Sage Publications: Thousand Oaks, CA, USA, 2002.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.