PROPOSED DESIGN FRAMEWORK FOR DIGITAL PIANO INTERFACES: A USER-CENTERED APPROACH

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ABSTRACT

With advances in music technology, digital pianos now provide high-quality sound simulation and increasingly diverse functions. However, interface design faces a growing challenge in balancing feature expansion with ease of use. Fixed physical buttons are limited in supporting complex parameter adjustments and may increase extraneous cognitive load, while touchscreen interfaces often lack the tactile feedback needed for embodied interaction. This study aims to propose a user-centered design framework to address these challenges.

A mixed-methods approach was conducted in two phases. In Phase 1, in-depth interviews with 10 experts were used to identify key operational preferences and functional layout principles. In Phase 2, a questionnaire survey was administered to 390 digital piano users. Cluster analysis

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identified three user groups: Advanced Experts, Intermediate Practitioners, and Novice Entry Users. Results showed that 71.0% of users preferred physical buttons during individual practice, with Intermediate Practitioners demonstrating particularly high reliance on physical controls (96.7%). However, a mismatch was observed between current interface designs and actual usage patterns. For example, although the Transpose function is often prominently positioned on control panels, 63.6% of users reported rarely or never using it, suggesting inefficient use of physical interface space. Additionally, simplified menus (58.5%) and one-touch shortcuts (55.4%) were identified as key factors for improving operational efficiency.

Based on these findings, this study proposes a three-layer design framework consisting of a Functional Layer, Interaction Layer, and Emotional Layer. The framework emphasizes reorganizing functions according to usage frequency and integrating tactile and visual feedback to reduce cognitive load and improve usability across different user groups.

Keywords: *Expert tacit knowledge, Kansei engineering, Visual compensation, Embodied cognition, Cluster analysis*

1 INTRODUCTION

With rapid advancements in music technology, Digital Musical Instruments (DMIs) have evolved from simple sound imitation into complex systems with high synthesis capabilities and precise parameter control. Unlike traditional acoustic instruments, the core characteristic of digital instruments lies in the physical separation of the "control interface" and the "sound generation engine" (Jensenius, 2022). While this separation offers design flexibility, it also reduces the physical coupling between the player and the instrument, making intuitive control a challenge (Hunt & Kirk, 2000; Wessel & Wright, 2002). Among numerous digital instruments, digital pianos have become the preferred choice for modern music education and home practice due to their simulation of traditional piano touch, silent practice capabilities, maintenance-free tuning, and diverse sound libraries. However, this multifunctionality has led to extreme complexity in the operation interface; while traditional piano keyboards provide excellent mechanical tactile feedback, their static physical layout struggles to correspond with increasingly complex digital functions and parameter adjustments (Jensenius, 2022).

To resolve the conflict between functional expansion and limited interface space, existing digital pianos often adopt a multi-level menu operation logic. This forces users to navigate through layers of menus, leading to increased "extraneous cognitive load" (Sweller, 2011), or to adopt a "second screen" strategy using external Apps. Although touchscreen interfaces offer layout flexibility (Shaer & Hornecker, 2010), they lack physical tactile guidance and damping. This increases the need for visual confirmation, conflicting with the "embodied cognition" nature of performance that emphasizes physical perception and eyes-free operation (McPherson, 2012; Schiavio & Menin, 2013). Furthermore, from the perspective of Kansei Engineering, when visual expectations do not match actual tactile feedback, it affects the user's emotional experience and pleasure (Yanagisawa & Takatsuji, 2015).

The theoretical dilemmas mentioned above are concretely embodied in high-end flagship models like the Yamaha P-525. Although the P-525 possesses a high degree of acoustic simulation maturity with its GrandTouch-S keyboard mechanism and CFX/Bösendorfer binaural sampling technology (Yamaha, 2023), its traditional "fixed physical button" interface, used for many years, has gradually become a structural bottleneck limiting User Experience (UX) upgrades. This "one-size-fits-all" design lacks flexibility when facing heterogeneous needs (Norman, 2013) and creates significant cognitive conflicts among users of different professional levels. For beginners, the complex and unguided panel configuration easily causes excessive cognitive load, hindering learning outcomes (Sweller, 1994, 2011). For professional performers pursuing efficiency, fixed buttons force them to make adjustments to key parameters through tedious "Menu Diving." Community feedback and professional reviews indicate that this design seriously interferes with the immediacy of stage performance and the state of flow (Welter & Ren, 2025).

To break through this limitation, this study attempts to address the rigidity of physical button operations, enabling the interface to be flexibly adjusted according to the user's contextual needs. On one hand, it provides simplified navigational guidance for novices, on the other hand, it grants experts the authority to define shortcuts, aiming to effectively reconcile the contradiction between "beginners' need for simplified navigation" and "professional players' pursuit of operational efficiency" (Jorritsma et al., 2015). Specifically, this study proceeds in two stages: first, gaining an in-depth understanding of the current usage of the Yamaha P-525 and its digital applications; second, analyzing user pain points in operating the integrated physical interface and virtual menus through task-oriented experiments and questionnaires; and finally, based on literature analysis and experimental results, proposing and validating a design proposal for a new interface, aimed at providing concrete, User-Centered design suggestions for the upgrading of the digital instrument industry.

2 METHODS

This study employs a mixed methods approach, conducted in two phases. Phase one involves expert interviews to deeply explore the operational perspectives and interface concepts of professional users. Phase two uses a questionnaire survey to validate the needs and preferences of large-scale users. Finally, data from both phases are integrated to summarize the key factors affecting the digital piano experience and derive a design framework.

2.1 Phase One: Expert Interviews

2.1.1 Participants

This phase adopted purposive sampling to recruit 10 participants aged 18 or older with experience operating electronic keyboards or digital pianos. Additionally, all interviewees were required to have at least 3 years of teaching experience to ensure their professional familiarity with teaching and practical usage. Interviews were conducted either in-person or online.

2.1.2 Interview Content

The interview content consisted of two parts: oral response and practical operation. The oral part covered three major dimensions: operational preferences, practical teaching pain points,

and future outlooks, comprising 11 open-ended questions. The practical part introduced the concept of Participatory Design, utilizing the CANVA Whiteboards collaboration platform. Interviewees were tasked with two specific activities: first, to rank a provided list of Yamaha P-525 functions based on their usage frequency and explain the rationale behind their ranking; and second, to interact with a top-down view of the digital piano by using a mouse to drag and rearrange or add function buttons, as well as adjust the screen size according to their operational preferences. These exercises aimed to create an "Ideal P-525 Interface Layout" (Figure 1) and concretize the interviewees' imagination regarding function zoning and operation logic.

Regarding data analysis, interview transcripts were analyzed using thematic analysis. Potential core issues were identified through coding and categorization. Two researchers independently coded the data to identify implicit and meaningful themes and concepts within the interviews. Reliability of the coding was ensured through repeated reading and the constant comparative method. Cohen's kappa coefficient was calculated to determine the consistency between the two coders. For the visual layouts produced in Canva, the heat zones of configuration and hierarchical logic of functional blocks, as well as function usage frequency, were summarized to serve as the basis for the subsequent questionnaire design.

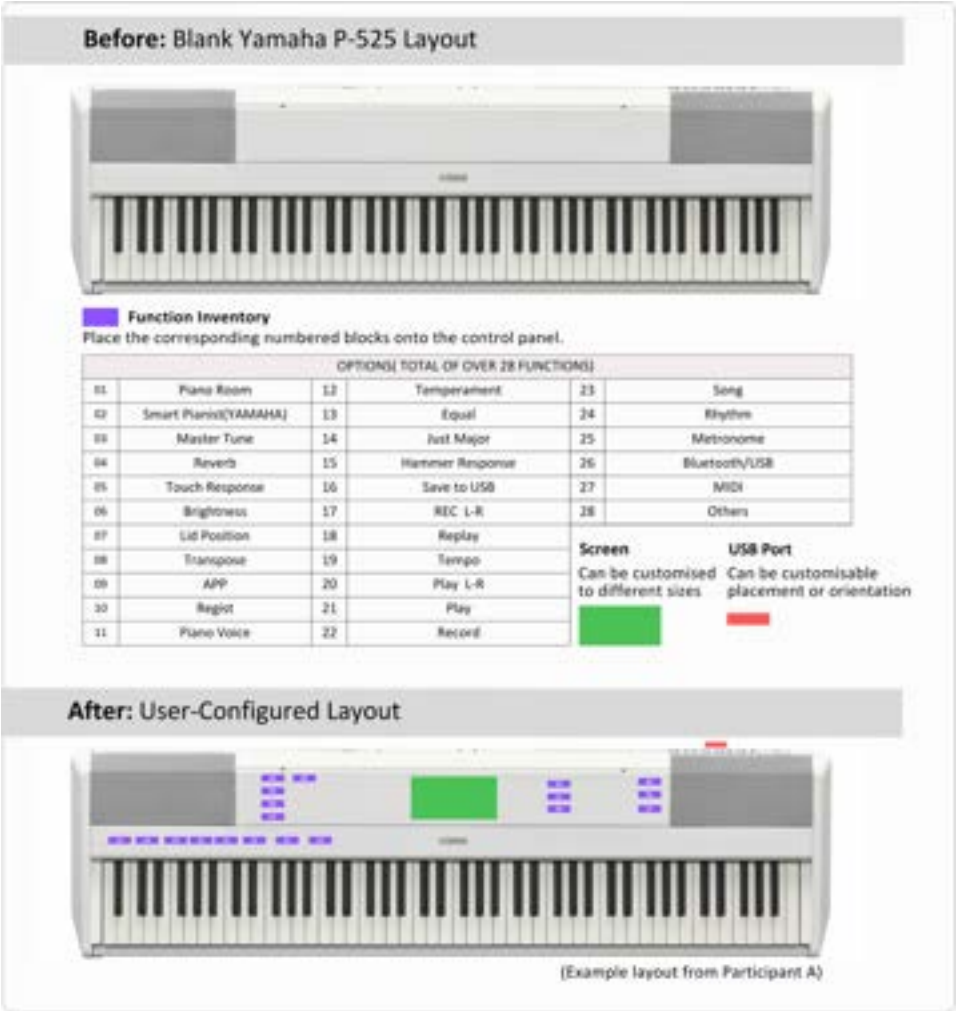

Figure 1. Schematic of the participatory design task using CANVA Whiteboards.

2.2 Phase Two: User Survey

This phase adopted an online questionnaire survey method, targeting social media forums and groups related to digital pianos as the main distribution channels. Participants were required to be 18 years or older and have experience operating digital pianos. To ensure the sample data possessed sufficient representativeness and reliability for subsequent statistical analysis, this study set corresponding sample size goals, ultimately collecting 390 valid questionnaires. The questionnaire items were based on the qualitative analysis results from the first phase of expert interviews, totaling 28 questions. The structure covered five core dimensions: identifying the participant's background and professional level through "Basic Information" and "Piano Learning History"; exploring "Operational Experience and Perception" to evaluate user satisfaction and cognitive load with existing interfaces; comparing user acceptance of physical buttons, touchscreens, and external Apps through the "Interface Type Preference" dimension; and finally collecting specific qualitative feedback through "Open-ended Suggestions".

2.2.1 Questionnaire Analysis

Quantitative data were analyzed using SPSS software. First, descriptive statistics were used to present the sample structure. Then, a Two-step cluster analysis was performed to group participants based on their learning history and skill indicators. Subsequently, one-way ANOVA was used to explore significant differences between different clusters in "Operational Experience" and "Interface Preference," thereby identifying the key needs of different groups to serve as the design basis for the interface framework.

3 RESULTS

3.1 Expert Perspectives

This study conducted in-depth interviews with ten experts. The interview data were subjected to thematic analysis by two researchers who did not participate in the interviews to ensure the objectivity and consistency of the coding process. The analysis results summarized five main themes, involving hardware and software design/application of digital pianos, external system connection, directions for improvement, and market positioning. Through interviews with digital piano teachers, the aim was to explore the actual usage scenarios and future development trends of digital pianos in the current market.

This study used thematic analysis for data processing. To ensure coding reliability, two researchers independently judged 709 coding units. The Cohen’s Kappa consistency test showed a coefficient of $\kappa = 0.823$, $SE = 0.019$, $\chi^2(1) = 37.489$, $p < .001$. According to the standards of Landis and Koch (1977), this indicates an almost perfect agreement between raters.

The interview results show that in practical application, digital piano core functions are the metronome, tone adjustment, recording, and automatic accompaniment. Especially in teaching scenarios, teachers often use these functions to improve student learning outcomes and correct performances. Regarding interface design and operational preferences, although Bluetooth and Apps (such as Smart Pianist) provide expandability and recording convenience, users generally still prefer intuitive physical button operations; models that rely excessively on App control (such

as the CSP series) present a higher barrier to operation. Regarding hardware specifications, interviewees emphasized screen visibility (e.g., font size for vision protection) and the necessity of USB/Bluetooth connectivity; screens that are too small may reduce the willingness of older adults or students to use them. regarding market positioning, although digital pianos are seen as an alternative to traditional pianos due to budget and space considerations, they still face competition from portable keyboard instruments. For future development, interviewees suggested continuing to optimize the authenticity of touch and tone, and providing Traditional Chinese interfaces and complete after-sales support to meet the needs of users ranging from beginners to professional musicians.

3.2 User Survey

3.2.1 Participant Demographics

This study collected 390 valid questionnaires. The participant profile shows the diversity of digital piano users. In terms of demographics, the gender ratio was fairly balanced (Female 53.8%, Male 46.2%). The age group was mainly concentrated in the middle-aged group of 36 to 55 years old, accounting for 72.9% of the total sample. Regarding identity, the vast majority of participants were office workers or freelancers (83.8%), while music majors or professional performers accounted for a very low percentage. Notably, in self-assessed playing skill, over 60% of participants (62.8%) considered themselves "Beginners," indicating that digital pianos are primarily used as learning or leisure tools for non-professionals. regarding brand ownership, Yamaha is the dominant market brand (54.6%), followed by Casio (13.3%) and Kawai (7.2%), while 28.2% of participants do not currently own a digital piano. regarding usage scenarios, the vast majority of users (75.9%) use digital pianos for "Personal Practice," followed by "Accompanying others' practice" (21.3%) and "Accompaniment/Ensemble" (16.4%), showing that personalized practice remains the core application scenario for this type of instrument.

3.2.2 Interface Preferences and Operational Challenges

Analysis of interface preferences across different usage scenarios shows that physical buttons remain the most relied-upon interaction mode in most situations. Particularly in the "Personal Practice" scenario, as many as 71.0% of users prefer using physical buttons, far higher than touch buttons (30.5%) and display screens (20.0%). However, as task complexity increases, such as in "Music Production" or "Accompaniment/Ensemble" scenarios, user acceptance of touch buttons, screen interfaces, and external Apps increases significantly. In terms of App usage behavior, Yamaha's Smart Pianist is the application with the highest penetration rate; about half of the users have experience using it, mainly for assisted practice and accompaniment. (Table X_Q 15)

The in-depth analysis of usage behavior further reveals a phenomenon of high idle rates for built-in functions, highlighting an asymmetry between "function supply" and "actual demand." Data shows that even for functions marketed as core features of digital pianos, their frequent usage rate (sum of "Often" and "Very often") is generally low. For example, "Transpose" and "Recording" functions, often placed prominently on the panel, have as many as 63.6% and 55.8% of users respectively stating they "Never" or "Rarely" use them. Even for relatively popular functions like "Rhythm" and "Voice/Change Voice," the proportion of high-frequency usage (weekly or more) is only between 25% and 30%.

Although physical buttons are the mainstream preference, the investigation into operational experience reveals potential cognitive load issues. Data shows that a significant proportion of users, when operating physical buttons (43.3%) and display screens (51.2%), indicate a need to "rely on the manual" to successfully complete operations (including Agree and Neutral options). Furthermore, the survey on design optimization needs points out that over 50% of users agree that "Simplified menus" (58.5%), "Clearer icons" (59.5%), and "One-touch shortcut keys" (55.4%) can effectively improve operational efficiency. This reflects that while existing interfaces can satisfy basic playing, there is still significant room for improvement in the intuitiveness of function navigation and information feedback.

3.2.3 Cluster Analysis

To deeply explore the heterogeneous needs of different user groups, this study employed Two-step Cluster Analysis. Based on variables such as learning history, usage frequency, self-assessed skill, and breadth of function usage, the 390 participants were divided into three groups with statistically significant differences. The three-cluster solution was determined by the Two-Step Cluster auto-clustering procedure, which showed the largest ratio of distance measures (2.72)—substantially higher than any other candidate solution. Analysis of Variance (ANOVA) results show that these three clusters exhibit significant differences in learning experience ($F=14.25$, $p<.001$), usage frequency ($F=16.76$, $p<.001$), skill level ($F=12.70$, $p<.001$), and function usage frequency ($F=42.81$, $p<.001$). The only variable with no significant difference was "Satisfaction," indicating that while different groups have different usage behaviors, subjective satisfaction with existing products tends to be consistent. (Table 1)

Table 1. One-way ANOVA and Post Hoc Results for Cluster Differences

Variable	Cluster 1 (n=186)	Cluster 2 (n=91)	Cluster 3 (n=113)	F(2,387)	η^2	Significant Post-hoc Differences (Scheffé)
Q7. Learning experience, M (SD)	2.39 (1.42)	1.75 (1.24)	1.64 (1.13)	14.25***	.069	1 > 2, 3
Q8. Usage frequency, M (SD)	2.45 (1.28)	1.97 (1.20)	1.67 (1.02)	16.76***	.075	1 > 2, 3
Q9. Self-assessed skill	1.80 (0.95)	1.46 (0.78)	1.33 (0.67)	12.70***	.059	1 > 2, 3
Q16. Feature usage frequency, M (SD)	2.96 (0.70)	2.35 (0.99)	2.11 (0.90)	42.81***	.175	1 > 2, 3
Q17. Satisfaction, M (SD)	3.59 (0.50)	3.54 (0.58)	3.53 (0.54)	0.64	.003	n.s.
Q18. Ease of use, M (SD)	3.62 (0.50)	3.47 (0.59)	3.33 (0.61)	9.26***	.046	1 > 3

Note. Values are presented as Mean (Standard Deviation). 1 = Cluster 1 (Advanced Expert Users); 2 = Cluster 2 (Intermediate Users); 3 = Cluster 3 (Novice Entry Users). η^2 = effect size. n.s. = not significant. *** = $p < .001$

3.2.4 User Profiles

The first group is "Advanced Expert Users" (n=186). This group accounts for the largest number of samples and is characterized by having the highest playing skills and usage frequency. They are extensively involved in diverse contexts such as teaching, creation, and ensemble performance. In terms of interface preference, they demonstrate the highest flexibility; not only are they familiar with physical buttons, but their usage rates for touch interfaces, screens, and Apps are also significantly higher than other groups, especially in music production and teaching contexts.

The second group is defined as "Intermediate Users" (n=91). Composed mainly of users with low-to-mid-level skills, their usage context is highly concentrated on "Personal Practice." The most significant characteristic of this group is their extreme reliance on "physical buttons"; in practice contexts, the proportion preferring physical buttons is as high as 96.7%, and they rarely use Apps or touch interfaces. This result suggests that for groups focused on practice, physical tactile feedback remains an indispensable core of interaction.

The third group is "Novice Entry Users" (n=113). This group consists mostly of beginners, and a proportion of 45.1% do not yet own a digital piano. They have the lowest function usage frequency and state "no involvement" in most advanced contexts (such as teaching, production).

Table 2 Cluster Labels and Descriptions

Cluster	Label	Key Characteristics	Interpretation
1 (n = 186)	Advanced Expert Users	• Highest levels of experience, frequency, and skill • Involved in the widest range of contexts (practice, teaching, production, ensemble) • Broad interface usage: physical buttons, touch, display, apps • Higher ownership of Yamaha and KAWAI, low proportion without a piano.	Experienced users with multi-purpose engagement, familiar with various digital piano functions, and versatile in teaching, practice, and creative production.
2 (n = 91)	Intermediate Users	• Lower skill/experience • Primarily focused on practice • Very strong reliance on physical buttons across contexts (practice, teaching, production) (80–97%) • Minimal use of touch, screen, or app interfaces.	Functional and efficiency-driven group preferring traditional physical controls; limited interest in advanced or digitalized features.
3 (n = 113)	Novice Entry Users	• Lowest learning experience and skill • Very limited engagement in teaching, production, ensemble, or other genres • Limited to basic practice contexts • High proportion of users with no owned piano (45.1%). • Rare use of advanced features, apps, or creative functions	Beginners or casual players, often without instrument ownership; lower engagement with digital features, focusing mainly on basic learning or occasional use.

4 DISCUSSION

Synthesizing the practical insights from the Phase One expert interviews and the quantitative data from the Phase Two large-scale questionnaire, this study follows the ISO 9241-210 Human-Centered Design process and incorporates considerations of user psychological expectations from Kansei Engineering to summarize a three-layer design framework comprising the "Functional Layer," "Interaction Layer," and "Emotional Layer." The following discussion delves into the design implications and empirical basis for each layer.

The Functional Layer is located at the bottom of the framework, covering hardware specifications, core technical capabilities, and information architecture. This study found a significant phenomenon of "function idleness" in existing digital pianos. Even for functions considered standard equipment, such as Transpose and Recording, over 50% of users stated they "rarely" or "never" use them. This data reveals an asymmetry between function supply and actual demand: when high-frequency functions (such as the metronome) are buried in secondary menus while low-frequency functions occupy the physical panel, the Interaction Cost exceeds the usage benefit, leading to excessive "Extraneous Cognitive Load" (Sweller, 2011) in the interface design.

Furthermore, cluster analysis results confirmed that users are not a homogeneous group. Although flagship models like the Yamaha P-525 attempt to satisfy all groups with a single interface, this "one-size-fits-all" strategy creates the design conflict described by Norman (2013): complex panel configurations deter Novice Entry Users (Cluster 3), while fixed layouts limit the operational efficiency of Advanced Expert Users (Cluster 1). Therefore, this study advocates that the Functional Layer should adopt "Frequency-Based Priority" and "Software Externalization" strategies. By transferring complex editing functions to Apps and allowing the physical interface to be dynamically defined based on user frequency, this approach can not only reduce the frustration caused by "Menu Diving" but also effectively reconcile the conflicting demands regarding operation depth between different clusters (Cluster 1 vs. Cluster 3).

The Interaction Layer focuses on the fluidity of the human-machine interface and the software-hardware integration experience. Research data shows a strong "Tactile Dependency," particularly in the "Personal Practice" scenario, where as many as 71% of users prefer physical buttons; notably, "Intermediate Users (Cluster 2)" exhibit a preference for physical interfaces as high as 96.7%. This supports the "Embodied Cognition" perspective of Schiavio and Menin (2013), which posits that a performer's thinking is closely linked to muscle memory, and purely touch-based interfaces lacking Haptic Feedback can easily interrupt the flow of performance.

However, this does not mean digital interfaces should be completely abandoned. Interview results reveal that users still rely heavily on visual confirmation during operation (e.g., confirming whether a function is active). Therefore, ideal interaction design should move towards a "Mixed Reality" mode, adopting a "Sync Feedback" strategy: retaining the physical damping of physical knobs to maintain performance intuition while providing real-time, large dynamic numerical feedback through digital screens. This design strategy resolves the physical coupling problem proposed by Hunt and Kirk (2000), satisfying modern users' dual needs for information transparency and digital convenience while preserving the feel of traditional instruments.

The Emotional Layer involves the user's psychological feelings and value judgments and is key to determining product satisfaction. The study found that users' pursuit of "authenticity" stems from a longing for traditional pianos, while the "headphone function" solves the psychological burden of fearing to disturb neighbors in modern living environments. From the perspective of Kansei Engineering, when visual expectations match actual tactile feedback, it can significantly enhance the emotional experience (Yanagisawa & Takatsuji, 2015).

Addressing the inherent limitation of digital instruments lacking a physical hammer structure, this study suggests using "Visual Compensation" to enhance Perceived Value. For example, presenting simulated physical dynamics (such as virtual hammer strike animations) through software interfaces can use visual information to compensate for the lack of physical entities, establishing a deeper emotional connection. The design implication of this layer is that digital pianos should not be seen merely as a stack of functions, but as carriers satisfying user psychological needs and identity, thereby elevating overall brand loyalty.

Taken together, these three layers translate into concrete design guidelines. At the Functional Layer, high-frequency functions identified in this study—such as the metronome and tone adjustment—should remain as dedicated physical controls, while low-frequency functions such as Transpose and Recording can be externalized to a companion app, reducing panel clutter without sacrificing accessibility. At the Interaction Layer, a Sync Feedback design—for example, a physical volume knob paired with a real-time numerical readout on an adjacent screen—preserves tactile intuition while resolving the visual confirmation needs identified in the interviews. At the Emotional Layer, Visual Compensation techniques, such as simulated hammer-strike animations, can enhance perceived authenticity despite the absence of a physical hammer mechanism. Together, these guidelines address the divergent needs of Advanced, Intermediate, and Novice user clusters identified in this study.

5 CONCLUSION

This study reveals the behavioral differences among distinct user clusters (Advanced, Intermediate, Novice) and proposes a three-layer Design Framework integrating "Functional, Interaction, and Emotional" aspects for digital piano interfaces. Future research is suggested to develop prototypes with reconfigurable interface functions to conduct usability testing, aiming to measure the specific effectiveness of this framework in reducing cognitive load and improving operational performance in actual operational tasks.

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