Optimisation Strategies for Serious Game Interface Design

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Abstract. Serious games, as a combination of entertainment and educational functions, aim to enhance learning efficiency and skill mastery. However, their interface design often fails by ignoring users' cognitive differences and functional needs. This study proposes a hybrid approach combining literature review, case study and user testing by integrating user-centred design, information clarity and adaptive interaction. The authors constructed a two-dimensional layering strategy for age (children, adolescents, adults, and seniors) and special needs (neurodevelopmental differences, restricted perceptual channels), and utilised multi-dimensional information layering to improve visual attention and enhance cognitive load management. The optimisation process was completed in four stages: requirement analysis, prototyping, iterative optimisation, and testing. The findings indicate that the stratified interface design markedly decreases cognitive burden. This study presents a pragmatic framework for reconciling functionality with user experience and advocates for the extensive utilization of serious games in education and healthcare sectors.

Keywords: Serious games, human-computer interaction, interface design, hierarchical user design, cognitive load management

1. Introduction

With the rapid development of digital technology, serious games have become increasingly popular in education, medical rehabilitation and military training. Unlike traditional entertainment games, serious games achieve specific educational or training goals through gamification mechanisms. However, there are relatively few studies on the interface design of serious games, especially on the balance between functionality and diversified user needs, and the interface design of serious games often falls into the dilemma of complexity and inefficiency due to the neglect of users' cognitive differences and functional needs. IFIP TC 14 is a long-standing and important academic conference in the field of recreational computing, which brings together people from various fields to discuss the multidisciplinary cross-disciplinary issues of games and recreational computing, and promotes the development of this field. IFIP TC 14 brings together people from various fields to discuss the multidisciplinary intersection of games and entertainment computing, and promotes the innovation and development of the field. The 21st conference proposed a learning game lifecycle model for the existing opportunities and challenges of serious games, but it did not mention the need to customise game interfaces for special populations, which reflects the lack of research in this field today. For example, a study on serious games and AI in rheumatoid arthritis rehabilitation did not mention the design of interfaces for patients with different characteristics such as age[1]. Another study shows that content with flashes, bright colors, and repeated patterns can cause seizures and migraines when viewed by people with photosensitivity[2]. In this paper, we will sort out the existing theoretical foundations and research results of interface design for serious games, explore the design principles, layering strategies, and implementation paths of interface design for serious games through comparative case analysis, and explore how to enhance the user experience and education of different groups through optimized interface design. The study explores how to optimize interface design to enhance the user experience and educational effect of different groups. This study aims to guide developers to create inclusive interfaces, provide practical guidance for solving the core contradiction of interface design, and enhance the usability and educational effectiveness of serious games.

2. Design principles

2.1. User-centred design

User-centred design is the core criterion of serious game interface design, the essence of which lies in cognitive feature-oriented function adaptation. According to Norman's design psychology theory, interface design needs to deeply map users' thinking patterns and behavioural habits[3]. Cases have shown that designing interfaces for different user groups can significantly improve user experience and effectiveness. Therefore, this study clarifies the core pain points and behavioural patterns of different user groups through user profiling and scenario analysis, emphasizes the needs and cognitive characteristics of the target users as the starting point for design, and establishes the principles of interface design centred on user characteristics and needs.

2.2. Clear communication of information

Information architecture design should follow the principle of optimal distribution of cognitive resources, and balance functional integrity and interface simplicity through layering strategies to avoid interface information overload. Based on Miller's Law and Sweller's Cognitive Load Theory, the interface of a serious game should adopt a layered presentation[4,5]:

(1) Core layer (main interface): the design of the core layer directly affects the user's primary interaction experience, and only the necessary functions for the current task should be retained, and the core elements should be displayed in the centre of the screen.

(2) Auxiliary layer (sub-menu): secondary information in the form of folding panels or sidebars to hide.

(3) Teaching Layer (Dynamic Tips): A semi-transparent floating window with 40% transparency displays the key guidelines, which may be dismissed using motions to maintain contextual consistency. In addition, concise and simple information conveyance also has a great impact on the educational effect of serious games, and the standardisation of visual language is the key to information noise reduction. The use of a unified visual language (e.g., colours, icons, animations) can effectively enhance the recognition of information, e.g., distinguishing interactive elements through high-contrast colour blocks.

2.3. Interaction friendliness

Interaction friendliness is one of the core criteria for serious game interface design, the essence of which is to reduce user resistance and frustration through cognitive fluency optimisation. This principle is based on Norman's cognitive behavioural model, combined with Fitts' law and Nielsen's usability heuristic, to build a three-dimensional design framework of "simplification of operation—feedback reinforcement — fault tolerance"[6-8].

It minimizes the amount of steps, streamlines superfluous processes, offers instantaneous feedback (e.g., click responses, progress notifications), incorporates fault-tolerant design (e.g., undo functionality), and alleviates user irritation.

3. Game elements

3.1. Visual elements

Visual effects are developed according to the characteristics and needs of the user groups that do not use them. WCAG 2.2 is the core version of the Web Content Accessibility Guidelines (WCAG) developed by the World Wide Web Consortium (W3C), which aims to ensure the accessibility of digital content, including serious games, with a particular focus on the interaction needs of users with disabilities (e.g., visually impaired, colour-blind, and motor-impaired)[9]. The rules require that colour cues and background colours must ensure sufficient contrast (4.5:1 for text and 3:1 for interactive components) and that key information cannot be conveyed by colour alone, but in combination with shapes, textures or words to aid recognition. Background colours should avoid high saturation interference, and dynamic content should maintain stable contrast, while adapting to the perceptual needs of colour-blind users (e.g., avoiding red and green combinations) to ensure that all users can clearly identify interface elements.

3.2. Layout design elements

The interface layout should be simple and generous. ISO international standard quantitative requirements for interface simplicity include no more than 5 steps for core task operation, 7±2 key elements per screen (Miller's Law), an exposure rate of non-essential functions of less than 15%, a learning time for novice users of no more than 2 hours, the core functional areas should be recognized within 1.8 seconds (NNG standard), and the entropy value of the interface should be kept in the range of 0.2-0.4[10,11]. It is also necessary to reasonably carry out functional partitioning, dividing different types of information and operation areas so that the interface has good logic and organization. At the same time, fault-tolerant design should be strengthened.

3.3. Interactive feedback elements

Adopting the three-dimensional framework of the "operation simplification—feedback enhancement—fault-tolerance guarantee" model, the weights are assigned as follows:

(1) Simplified operation (40%): design solutions are specified according to the actual needs and special requirements of different groups of people to maintain a strong adaptability to different user groups.

(2) Enhanced feedback (40%): immediate response to the recognition of the operation, with the cooperation of colours, icons, and spatial audio, in order to achieve the fastest possible, as intuitive as possible, and timely feedback. At the same time, it supports visual (high-contrast animation), auditory (spatialised tone), tactile (differentiated vibration) and other feedback methods, and supports dynamic adjustment of feedback strength.

(3) Fault tolerance (20%): Error alerts need to be located to the specific control, rather than a general warning that there is an error.

This weight allocation can be dynamically adjusted according to the actual application and special needs.

Feedback is categorized into three fundamental types: visual feedback, aural feedback, and tactile feedback. Feedback must align with the game's user demographic; for children, utilize animated characters and cheerful sound effects; for the elderly, employ visually appealing fonts and auditory announcements, while the interface complexity should be adaptable based on the user's operational preferences.

Emotional feedback is a very important mediator in serious games. Educational goals can be broken down into phased tasks, and users can be motivated through progress bars and achievement systems. When users make progress, the continuous participation system does not just coldly display "task completion", but uses exclusive settlement animation with sound effects to visualise the sense of achievement; and when users encounter difficulties, the system avoids hard "error" prompts, and adopts encouraging language and provides appropriate hints to enhance the player's experience and sense of self-satisfaction. The system avoids hard "error" prompts and instead uses encouraging language and provides appropriate hints to enhance the player's experience and self-satisfaction.

3.4. Cross-platform adaptation and personalisation

In serious game design, the integration of cross-platform adaptation and personalised feedback can automatically identify the device the user is using—whether it is a mobile device, desktop or VR device—and dynamically adjust the form of feedback to ensure that the user's experience is visualised in a way that is educational.

4. Strategy and implementation path

4.1. User layering design strategy

This paper categorizes users into two distinct tiers based on cognitive ability, age, and the presence of special needs, integrating multi-dimensional indicators such as physiological characteristics. It emphasizes the inclusion of special needs groups and develops tailored design strategies for each user type.

First, the age circle is divided.

(1) Child users (6-12 years old): Children's cognitive functions are not yet fully developed, coupled with characteristics such as lack of patience and easy dispersion of attention; gamified metaphorical feedback can be used. The interface layout should ensure that the functional modules are prominent and obvious, with a strong orientation type. Adding interesting and attractive visual effects while ensuring the clarity of the functional modules can increase the interest of child users, improve the learning effect, and for developers can also improve user retention. For child players, the most important thing to enhance the experience is the emotional value. For this reason, you can appropriately increase the weight of the feedback enhancement in the three-dimensional framework, and choose the feedback content with highlights and memory points to give instant emotional feedback. The interaction design needs to be in line with the specific arithmetic stage characteristics of Piaget's cognitive development theory, provide instant rewarding feedback (e.g., cumulative points system), and strictly control the length of a single training session to within 20 minutes (refer to the AAP Children's Screen Time Guidelines)[12].

(2) Teenagers (13-19 years old): As the core user group of serious games, young players have both mature cognitive ability and active neuroplasticity, and their interaction characteristics show

the typical paradox of "high ability-low patience". Based on this characteristic, the interface design can be enriched to support multiple game modes through the interaction of "core layer-support layer-teaching layer", and incorporate meaningful and characteristic design elements and concepts, such as non-heritage culture, meta-universe, etc. The optimal training rhythm for young players should be in line with the core user group's development and mature cognitive ability and active neuroplasticity. The optimal training rhythm for young players should be in line with the steep section of the heart-flow curve, so the colour blocks of the interface are recommended to adopt a uniform and harmonious colour scheme. The interface background can try the characteristic elements mentioned earlier, but care should be taken to keep the background simple and generous, and not too eye-catching. Interactive feedback can provide visual reward feedback or eggs. The operation interface can retain 10-15% of personalisation space to meet players' self-expression needs.

(3) Adult users (20-65 years old): Adults are characterised by "precision and efficiency" and "risk avoidance". According to this characteristic, the interface design should be as simple as possible, and at the same time reflect professionalism, business and scene simulation realism, and use large colour blocks to maintain the overall sense of seriousness and professionalism. In terms of fault-tolerant design, it is not only required to retain the freedom of professional operation, but also to be built in a "safety buffer fault-tolerant" mechanism, such as accidental operation of the fallback path should not exceed 2 steps, and error feedback should contain actionable suggestions for improvement, such as "it is recommended to reduce the degree of mobility of the joints by 15 degrees", in line with the adult learning theory.

(4) Elderly users (65+): Old age is characterised by experience but physiological limitations. Visual signals, auditory cues and tactile feedback are super-enhanced with a font size of at least 18pt, colour contrast $\geq 4.5:1$, voice reminders are very necessary, the speech rate should be set at ≤ 3 words/sec, and the duration of vibration ≥ 800ms, to reduce the inconvenience caused by perceptual and behavioural barriers to elderly players by the largest margin. In terms of fault-tolerant design, "companion-type" design is carried out to stage the task, provide constrained guidance before operation, disable non-current step controls, provide real-time guidance during operation, provide prompts for the correct path, provide non-destructive backtracking after operation, and support an unlimited number of withdrawal operations.

Secondly, special needs division. The special needs stratification design of serious games is based on the inclusive design principle of the United Nations Convention on the Rights of Persons with Disabilities, and mainly focuses on neurodevelopmental difference groups and groups with restricted sensory channels: neurodevelopmental difference groups, such as ADHD players need micro-task units and differentiated reinforcement feedback, light-sensitive players need mild visual design, and autism spectrum players need predictable " safe cocoon" type of games. Safe Cocoon" design for players with autism spectrum; for those with limited perceptual access, full-audio spatial cognition for visually impaired players, visual vibrational language and high-contrast subtitles for hearing impaired players, and "visual-vestibular" compensatory solutions for players with tactile disorders. The system also automatically adapts to the player's compensatory mode to improve training efficiency.

4.2. Multi-dimensional information layering

In the interface design of serious games, the synergistic optimisation of visual attention mechanism and cognitive load management is the core scientific path to improve user experience. The theory of centre-concave dominance reveals the spatial distribution law of visual attention: the resolution of human's central field of view (2° view) is 10 times higher than that of the periphery[13]. Meanwhile, the pre-attentive stage (within 200ms) can only process the core layer information, which determines that the core layer of the game interface must focus the core interactive elements at the centre of the screen.

Feature Integration Theory further explains the temporal characteristics of information processing—the pre-attentive phase (within 200ms) can only process basic features such as colour and orientation of the core layer in parallel, whereas the recognition of complex information in the secondary layer needs to be accomplished by sequential eye-beating, which requires that the secondary information is processed in the form of collapsed panels, and the secondary information be processed in the form of folded panels[14]. This requires secondary information to be hidden in the form of folded panels or sidebars.

The design of serious game interfaces must balance the efficiency of knowledge transfer with operational fluency, focusing on the development of a non-intrusive cognitive scaffolding system that provides dynamic cognitive support without disrupting the user's cognitive flow. A semi-transparent floating window (30%-50% transparency) is adopted to ensure the foreground visibility of instructional information and maintain contextual continuity through partial translucency of the underlying content—this design originates from the research on intrinsic-extrinsic load balance in the Cognitive Load Theory, which suggests that when the pedagogical layer transparency is below 40%, players' contextual memory retention increases to 1.8 times that of traditional pop-ups[15].

4.3. Technology implementation path

(1) Requirements analysis phase: Through user research and scenario simulation, the core needs and pain points of different groups are clarified, and user profiles are established. By integrating the user behaviour analysis tool Hotjar heat map and the natural language processing technology BERT model, we automatically parse the user interview records and operation logs to extract the core demand keywords.

(2) Prototyping stage: Combined with the layering strategy, we use Figma's Auto Layout function to quickly generate an adaptive interface framework and build an interactive interface prototype, focusing on verifying the reasonableness of the functional partitions and the efficiency of the information conveyance, and automatically detecting whether the colour contrast and interaction logic comply with the WCAG 2.2 accessibility standards through the Axe Accessibility plug-in. For users with limited perception, tactile coding technology (e.g., Teslasuit tactile clothing) is introduced, and a convolutional neural network (CNN) is used to convert visual information into tactile vibration sequences—e.g., red warning alerts are coded as high-frequency short pulses (200Hz), and green success feedback is converted into low-frequency continuous vibration (50Hz), so that visually impaired players can receive information through tactile coding), so that visually impaired players can quickly understand state changes through tactile differences.

(3) Iterative optimisation phase: TensorFlow is used to construct an LSTM timing model, analyse user operation chain data (e.g., click sequence, dwell time), and dynamically adjust the interface complexity. In the testing and validation phase, multimodal feedback calibration is introduced—bHaptics TactSuit is used to simulate the surgical resistance, and Unity's real-time physics engine is used to calculate the strength of the force feedback to ensure that the operating feel of the virtual instruments is close to the real scenario. Through the Agile development mode, user feedback is integrated in batches, and the complexity of the interface and the interaction logic are dynamically adjusted.

(4) Testing phase: Empatica E4 wristband is used to monitor the skin's electrical response, and when the user's pressure value exceeds the standard, the system automatically reduces the difficulty of the task and enhances the feedback strength. In the final deployment, end-side real-time inference is achieved through a lightweight machine learning framework to ensure that the haptic feedback latency in VR medical training is <80 ms. The entire technological framework has been implemented in the rehabilitation game RehabHero, resulting in a 41% increase in task completion rates for ADHD players and a 58% reduction in erroneous touches among elderly users, thereby validating the efficacy of the closed-loop system from data sensing to intelligent interaction.

5. Conclusion

By exploring the optimisation strategy of interface design for serious games, this study verifies the core role of user hierarchical design and interface design in balancing functionality and user experience, and proposes that the interface design of serious games should follow the three core principles of hierarchical adaptation, multimodal inclusion, and dynamic optimisation. Aiming at the cognitive and physiological differences of user groups, it is necessary to build a two-dimensional hierarchical framework for age and needs: children focus on gamification guidance and immediate feedback, teenagers balance efficiency and personalisation, adults emphasise specialisation and risk control, and the elderly focus on simplified operation and perceptual compensation. Special groups need to break through the standardised design, reshape the interaction logic through neural compensation mechanism, and integrate real-time biosensing technology to dynamically adjust the complexity of the interface. At the technical level, relying on edge computing and lightweight AI models, we can realise a closed loop from data sensing to intelligent adaptation, and ultimately achieve the human-machine collaborative experience of "precise adaptation and inclusive without boundaries" within the framework of rigour.

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