Model Construction and Implementation of a VR System for Reading Promotion and Cultural Dissemination of Ancient Chinese Books Postprint

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Abstract

[Purpose/Significance] This study aims to leverage VR media technology to overcome or mitigate the problems of limited access to ancient books, difficulties in Classical Chinese comprehension, lack of specialized knowledge, insufficient specific cultural background knowledge, and inadequate reading motivation among general readers, thereby promoting ancient book reading and cultural dissemination. [Methods/Process] Employing literature research methods to analyze and synthesize relevant theories in cognitive science and educational technology, this study proposes design principles and a theoretical model for VR ancient book systems. Based on a single case analysis, a system prototype was designed, developed, and tested. Finally, experimental methods were employed to collect evaluation data via questionnaires to verify the usefulness of the design principles and model. [Results/Conclusion] The research outcomes include VR ancient book system design principles, a VR ancient book system theoretical model, the first application prototype of a VR ancient book system, and a VR ancient book system usage theory, which can serve as a reference for subsequent researchers and designers engaged in VR ancient book system research and design.

Full Text

Preamble

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Constructing and Implementing a VR System Model for Promoting Chinese Ancient Book Reading and Cultural Dissemination

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Abstract: [Purpose/Significance] This research aims to leverage VR media technology to overcome or mitigate barriers faced by general readers in accessing and understanding Chinese ancient books, including difficulties in obtaining materials, comprehending classical Chinese, lacking specialized knowledge, missing cultural context, and insufficient reading motivation, thereby promoting ancient book reading and cultural dissemination. [Method/Process] Through literature review, we analyzed relevant theories in cognitive science and educational technology to propose design principles and a theoretical model for VR ancient book systems. Based on a single case study, we designed, developed, and tested a system prototype, and finally employed experimental methods using questionnaires to collect evaluation data and verify the usefulness of our design principles and model. [Result/Conclusion] Our contributions include: (1) VR ancient book system design principles, (2) a theoretical model for VR ancient book systems, (3) the first application prototype of a VR ancient book system, and (4) a theory of VR ancient book system usage. These outcomes can serve as valuable references for researchers and designers engaged in VR ancient book system research and development.

Keywords: VR; virtual reality; ancient books; reading promotion; cultural dissemination; embodied cognition
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General readers face significant barriers when engaging with Chinese ancient books, including limited access, insufficient classical Chinese proficiency, lack of specialized knowledge, unfamiliarity with historical cultural contexts, inadequate bibliographic search skills, and weak reading motivation. Consequently, physical ancient books and digital databases remain largely confined to literature and history specialists [1-2], creating a bottleneck for popular dissemination.

Virtual Reality (VR) represents an immersive reading medium that engages multiple sensory channels, provides 身临其境 (shenlinqijing) reading experiences, reduces reading difficulty, and enhances reading interest [3]. As a forward-compatible medium, VR encompasses conventional text, image, audio, and video presentation functions of print and electronic media while additionally supporting 3D models and VR scene experiences, making reading content more intuitive and engaging. Current VR book design frequently employs VR scenes to demonstrate difficult or abstract concepts within texts [4].

VR can truly “bring ancient book characters to life.” VR ancient book practices

have revitalized traditional culture. For instance, the 2018 "Cefu Qianhua—Guangxi Zhuang Autonomous Region's Collection of National Precious Ancient Books Special Exhibition" [5], co-organized by the National Library (National Ancient Books Preservation Center) and Guangxi Department of Culture and Tourism, launched a VR+Guangxi ancient books experience project enabling readers to learn intangible cultural heritage skills from ancient craftsmen and appreciate the architectural beauty of Guangxi's distinctive residential buildings. The 2019 First Chen Village Three-Character Classic Enlightenment Culture Week introduced the "Qu Shizi and the Three-Character Classic" VR cultural experience project [6], transporting readers to ancient life scenes where they could learn traditional Chinese virtues and historical stories conveyed in the Three-Character Classic under the guidance of virtual characters. Such practices present obscure ancient book content to readers in tangible, accessible ways, achieving the effect of resurrecting ancient texts [7].

Current domestic and international VR book research predominantly focuses on VR-based reading scene construction [8-9], children's books [10-11], travel books [12-13], educational books [14], book publishing [15-16], cognitive utility [17-18], multimedia resource design for VR books [19-20], interaction design [21-22], and evaluation metrics [23-25]. However, no VR ancient book system design principles or models have yet been proposed specifically to overcome or mitigate Chinese ancient book reading barriers.

Building upon existing research and practice, this study aims to address current problems faced by general readers in ancient book reading. Using literature review methods, we analyzed relevant theories in cognitive science and educational technology to propose VR ancient book system design principles and models to guide prototype development and testing. Employing experimental methods, we collected evaluation data through questionnaires to explore the usefulness of our system design principles and model. The primary research question this study seeks to answer is: How can we construct a VR system model for promoting Chinese ancient book reading and cultural dissemination?

2 Related Theories

2.1 Cognitive Load Theory

Cognitive load refers to the total amount of information processed and stored in working memory during cognitive task processing at a given time [26], typically divided into intrinsic cognitive load, extraneous cognitive load, and germane cognitive load [27-28]. Intrinsic cognitive load is primarily influenced by material difficulty (more difficult content yields higher load) and personal prior knowledge (richer prior knowledge reduces difficulty). Extraneous cognitive load represents load beyond intrinsic load, arising when individuals process information irrelevant to learning materials, thereby increasing total cognitive load. Germane cognitive load comprises useful load that facilitates knowledge association construction, content internalization, and transformation into memory during

learning [29].

Effective multimedia learning design should reduce intrinsic cognitive load, decrease extraneous cognitive load, and increase germane cognitive load while ensuring total load remains within individual capacity [26,30-31].

2.2 Cone of Experience Theory

Originally proposed by American audiovisual educator E. Dale [32], the "Cone of Experience" theory has been interpreted and modified by numerous scholars to guide multimedia instructional resource design. The theory categorizes multimedia resources into ten levels and three types of experience based on content abstraction degree [33-34] (see Figure 1 [Figure 1: see original paper]). Tower base experiences are most concrete with highest sensory participation, while content becomes increasingly abstract toward the apex, with lower sensory participation and higher demands on information processing capability. The three experience types have no inherent difficulty or superiority distinctions and are typically used in combination. Therefore, multimedia content design should integrate diverse multimedia resources according to content difficulty and target audience differences to achieve specific learning effects [35].

2.3 Multimedia Learning Cognitive Theory

Educational psychologist R. Mayer's Cognitive Theory of Multimedia Learning posits that linguistic and pictorial multimedia information enters human working memory processing through auditory and visual sensory channels via selection mechanisms. The brain actively draws upon prior knowledge from long-term memory, integrating it with auditory and visual information in working memory to generate new knowledge stored in long-term memory [36], as shown in Figure 2 [Figure 2: see original paper].

This theory has three fundamental assumptions: the dual-channel assumption, limited capacity assumption, and active processing assumption [37]. The dual-channel assumption holds that human information processing consists of two independent channels—one for language and one for visual imagery—that can cross-integrate information in working memory, reducing single-channel cognitive load when operating simultaneously. The limited capacity assumption states that individual processing channels have finite capacity in specific contexts; continuous information input creates load, while multiple channels can process more information with reduced individual channel load. The active processing assumption maintains that cognitive processes undergo selection, organization, and integration, requiring subjective initiative manifested as autonomous control, interaction, and participation. These theories and assumptions provide design foundations and principles for multimedia instructional design aimed at achieving specific learning effects.

2.4 Embodied Cognitive Theory

Embodied Cognitive Theory posits that cognition emerges from the interaction between bodily structure/function, sensorimotor systems, and the environment [38], representing a multi-channel integrated processing of environmental information perceived by the body [39]. It defines body, brain, and environment as three essential elements for cognition generation [40]. The theory features three distinct characteristics: (1) cognition is embodied, inseparable from physical corporeality, with bodily structure, state, and physical properties determining cognitive breadth and depth [41-42]; (2) cognition is experiential, requiring interaction with the external environment to form bodily experiences [43-44]; and (3) cognition is situated, with environment/context being essential conditions for generating embodied cognition.

Scholar D. Allport et al. [45] proposed the multi-channel hypothesis, suggesting different sensory channels occupy distinct cognitive processing resources. Using the human body as a cognitive medium, sensory channels serve as interfaces between brain and environment, with multi-sensory information acquisition yielding far superior cognitive effects compared to Mayer's dual-channel model. Additionally, scholars Lu Lu et al. added the somatosensory channel to propose multi-channel selection and integration mechanisms, demonstrating cognitive processes under visual, visuo-tactile, and tactile-auditory integration [3], and verifying that VR system users' cognitive load decreases as the number of cognitive channels increases [46].

3 VR Ancient Book System Design Principles

From a cognitive load theory perspective, barriers general readers face in ancient book reading—classical Chinese comprehension, specialized knowledge understanding, and socio-cultural context—constitute intrinsic cognitive load. This load stems from: (1) numerous difficult points in reading content creating heavy cognitive processing demands, and (2) limited prior knowledge in general readers that cannot support information integration in working memory. The key to VR ancient book design lies in reducing cognitive load while enhancing reading interest. We propose five design principles:

3.1 Integrating Diverse Multimedia Resource Annotations

Based on the Cone of Experience theory, diverse multimedia resources should be combined to annotate complex knowledge points [47], organically integrating three types of experiential resources: text, images, video, audio, 3D models, and VR scenes to optimize reading effects. Leveraging VR's multi-channel information processing advantages, diverse multimedia resources can fully engage readers' visual, auditory, and tactile systems, reducing cognitive load for ancient book content.

3.2 Employing Cultural Tourism-Related Resource Annotations

According to cognitive load theory, appropriate germane cognitive load positively benefits readers' understanding of ancient book content. Ancient books contain rich traditional cultural elements—historical figures, artifacts (utensils, clothing, objects, calligraphy, paintings), architecture, institutions, regulations, customs, etc. These knowledge points can be revealed or visualized using related historical materials, documentaries, archaeological artifacts, and cultural heritage site resources.

3.3 Decomposing Reading Tasks

Complex ancient book content and lengthy texts easily induce reading fatigue, affecting reading effectiveness [48]. Based on the limited capacity assumption in multimedia cognitive learning theory, continuous or prolonged information input creates high cognitive load. The segmentation principle can decompose tedious, heavy tasks [49], enabling readers to selectively understand key points according to their own pace, freeing cognitive processing space [50] and reducing cognitive load. However, decomposition should also emphasize coherence principles to reduce external information interference with learning tasks.

Building upon segmentation and coherence principles, VR ancient book design adopts a "point-line" combination approach to segment ancient book content. "Points" represent the smallest knowledge units in ancient books, such as keywords critical to understanding sentences; "lines" represent narrative units, such as story segments, events, or plotlines.

3.4 Constructing Embodied Reading Scenes

Constructing embodied reading scenes aims to satisfy the environmental requirements of embodied cognitive theory and the "learning by doing" experience demands of the Cone of Experience theory. This requires VR ancient book design to: (1) build embodied reading venues that simulate library functions and forms, designing courtyards, VR ancient book libraries, reading rooms, bookshelves, desks, and ancient book displays to provide authentic reading contexts; and (2) contextualize abstract textual content by introducing VR scenes to demonstrate complex knowledge points, enabling readers to perceive intuitive information immersively and obtain learning-by-doing experiences and embodied cognition.

3.5 Providing Autonomous Interaction Control Functions

According to the active processing assumption in multimedia learning cognitive theory, effective reading requires mobilizing readers' autonomous knowledge processing capabilities. In multimedia environments, readers must be granted autonomous interaction control capabilities—also essential conditions for achieving embodied cognition through human-VR environment interaction [51].

Interaction control functions should be designed based on different scene objects and multimedia interaction targets, enabling readers to perform corresponding physical actions in specific contexts. Common interaction functions include clicking, zooming, pulling closer, pushing away, rotating, walking, and touching.

4 VR Ancient Book System Functions

4.1 VR Ancient Book System Model

To address the problems targeted by the VR ancient book system, the system comprises three modules: VR ancient book reading environment, VR ancient book content, and VR ancient book functions. The corresponding design theories, principles, and specific functions for each module are shown in Figure 3 [Figure 3: see original paper].

4.2 Research Case

The system prototype uses "Old Book of Tang: Biographies 1: Imperial Consorts 1: Emperor Xuanzong's Yang Guifei" as a case study. Using qualitative thematic and narrative analysis methods, we extracted knowledge elements and storylines from the ancient text [52]. Knowledge elements were categorized into six themes: physical objects, cultural customs, institutions, locations, characters, and regulations. Storylines included five narrative plots: father taking son's wife, exclusive imperial favor, Yang family corruption, ruler-minister misgovernance, and An Lushan Rebellion. These knowledge elements and storylines were annotated according to the VR ancient book system model design and functions described in Section 4.1.

4.3 VR Ancient Book System Prototype Demonstration

Based on the VR ancient book system model in Section 4.1, we designed and developed a VR ancient book prototype. Figure 4 [Figure 4: see original paper] shows the VR ancient book reading environment constructed based on embodied reading scene principles. Figures 5 [Figure 5: see original paper] and 6 [Figure 6: see original paper] demonstrate ancient book content annotation designed according to principles of diverse multimedia resource integration, cultural tourism resource annotation, and task decomposition. Figure 5 shows VR ancient book knowledge element annotation, while Figure 6 shows VR ancient book storyline annotation. Figure 7 [Figure 7: see original paper] displays diverse multimedia resources for knowledge element annotation, and Figure 8 [Figure 8: see original paper] shows related cultural tourism resources used for annotation.

5 VR Ancient Book System Testing and Evaluation

5.1 Laboratory Testing

5.1.1 Testing Environment

Experimental equipment included: Alienware computer host (1 unit), HTC

VIVE PRO headset (1 set), HTC wireless upgrade kit (1 set), HTC VIVE PRO controllers (1 pair), HTC VIVE trackers (4 units), Samsung display (1 unit), and reading chair (1 unit).

5.1.2 Testing Process

Each development stage underwent verification: whether engineering tasks were completed, functions operated properly, and requirements aligned with model design. If qualified, the process advanced to the next stage; otherwise, modifications were made until satisfactory. Testing spanned from July 2020 to November 2020, completing 17 laboratory tests by the pilot evaluation stage.

5.2 Field Evaluation

Field evaluation comprised two phases—pilot evaluation and formal evaluation—conducted with subjects outside the laboratory.

5.2.1 Pilot Evaluation

(1) Purpose: To identify problems in evaluation procedures, system application, and questionnaire design from readers' perspectives for timely optimization before formal evaluation.
(2) Evaluation Process: Three subjects were recruited. Each experiment lasted approximately 80 minutes. Subjects signed informed consent forms, read experimental guidelines, understood procedures and tasks, and then participated in the computer-based experiment. The experiment included a pre-test (reading paper ancient books and completing questionnaires to identify personal reading barriers) and a computer test (learning VR controller functions, experiencing the VR ancient book system, and completing tasks). The computer test questionnaire used a five-point Likert scale and open-ended questions covering three dimensions: VR environment, VR ancient books, and VR ancient book system's usefulness in overcoming reading barriers. Tasks included: (1) touring the VR ancient book library courtyard to evaluate environmental elements; (2) entering the VR library and reading room, approaching bookshelves, picking up target ancient books, and entering reading mode to evaluate the library scene; (3) flipping through VR ancient books, viewing knowledge element annotations, viewing storyline maps, and listening to storyline explanations to evaluate content, functions, and barrier mitigation effectiveness.
(3) Time: Pilot evaluation was conducted on October 22, 2020.

5.2.2 Formal Evaluation

(1) Purpose: To verify the VR ancient book system prototype's usefulness in solving ancient book reading barriers, identify usage problems, and confirm the usefulness of design principles and models while identifying design issues to avoid.
(2) Subject Recruitment: Formal evaluation recruited 63 Sun Yat-sen University students, completing 62 valid experiments and collecting 62 valid questionnaires. Subjects were 56% male and 44% female, predominantly aged 18-24 (87.1%), from diverse majors. 48% had never used VR, 42% rarely used VR, and 100%

had never read VR books.
(3) Evaluation Process and Tasks: Formal evaluation followed the same procedure and tasks as pilot evaluation. Figure 9 [Figure 9: see original paper] shows subjects experiencing the VR ancient book system, including controller training, environment experience, bookshelf interaction, and reading.
(4) Evaluation Time: November 22-27, 2020.
(5) Quantitative Analysis Results: Statistical descriptive analysis of questionnaire data across three dimensions (VR environment, VR ancient books, system usefulness in overcoming barriers) showed mean values above 4, between "agree" and "strongly agree," indicating very positive attitudes toward the prototype's usefulness. Cronbach's Alpha reliability analysis yielded an overall α coefficient of 0.941, with each dimension's α exceeding 0.8, demonstrating ideal data quality and high reliability. Experimental data confirmed that VR ancient book system design principles and models have significant utility in overcoming or mitigating general readers' ancient book reading barriers.

6 Results Discussion

Based on design principles, we discuss VR ancient book system usage theory, elaborating on the system's usefulness and existing problems in addressing general readers' ancient book reading barriers.

6.1 Integrating Diverse Multimedia Resource Annotations

6.1.1 All Resource Types Positively Contribute to Revealing Reading Difficulties

Representative subjects like P32 noted that "multimedia methods help understand the original text," while P7 stated that "beyond text, audio, video, images, and 3D facilitate understanding." From multimedia learning cognitive theory analysis, information presented through different multimedia resources is acquired, organized, and integrated through different cognitive channels, with each channel forming distinct mental representations (e.g., visual, linguistic, tactile) during decoding. These different mental representations cannot substitute for one another. Furthermore, cognitive agents must cross-integrate information with different mental representations based on prior knowledge to achieve meaningful reading comprehension [50]. From the Cone of Experience theory perspective, diversified multimedia resource design effectively integrates abstract, observational, and learning-by-doing experiences, yielding better reading effects than single-experience resources.

6.1.2 Multi-Channel Information Presentation Significantly Outperforms Dual-Channel, Making Cognition More Intuitive and Simpler

Representative subjects like P42 noted that "for unfamiliar words, the system provides concrete scene models, and 3D models for objects, facilitating intuitive understanding," while P52 stated that "scenes can vividly recreate situations, making things easier to understand." Multi-channel information presentation's superiority over single-channel represents a cognitive channel effect:

multi-channel information, after mental representation processing, can cross-integrate in working memory [50], generating different cognitive chunks. Compared to single-channel acquisition, multi-channel information provides broader coverage, creates more information chunks during processing, reduces reading content cognitive load, and enriches understanding.

6.1.3 3D Models and VR Scene Presentation Significantly Outperform 2D Content, Enriching and Interesting Cognition

Representative subjects like P2 commented that "scene transitions and model grabbing are very interesting," while P11 noted that "3D models/scenes are very interesting, with many dynamic scenes." Compared to 2D resources, 3D/VR scene information processing engages additional sensory channels, providing richer information. Moreover, 3D models/VR scenes support deep reader interaction, allowing readers to gain pleasurable psychological experiences through autonomous control of multimedia resources.

6.1.4 Information Resources with Multiple Interaction Functions Yield Better Presentation Effects and Deeper Cognition

Unlike text, images, video, and audio with simple zoom, pull, pause, and play functions, 3D models allow readers to hold, rotate 360°, observe, appreciate, and zoom, while VR scenes enable walking, viewing, jumping, and embodied perception of entire environments. Consequently, subjects rated 3D models/scenes highest and most memorable. From embodied cognitive theory, human-environment interaction requires multi-sensory system engagement, meaning interactive annotation resources are more likely to occupy multiple cognitive channels, enabling the brain to acquire more information and form deeper cognition and memory [3].

6.1.5 Readers Exhibit Different Multimedia Resource Type Usage Styles

According to the "learning preference hypothesis," readers have different style tendencies in information perception channels. The typical VARK model [53] categorizes learning styles into visual, auditory, read/write, and kinesthetic. This model reflects that readers with different cognitive abilities and learning styles adapt differently to multimedia resources. For example, visual learners benefit most from movies, flowcharts, and images; auditory learners prefer audiobooks; read/write learners favor lecture-style learning and note-taking; kinesthetic learners benefit most from participatory, on-site experiences [54]. The most popular multimedia resource type in VR systems is 3D models/scenes, indicating kinesthetic reading is most welcomed. However, some subjects expressed preferences for other media types, such as P6 suggesting annotations should "focus on text with images and audio as supplements," and P5 recommending "adding note-taking functionality." These preferences suggest P6 and P5 are likely read/write-style learners. Therefore, VR ancient book system design should incorporate diverse multimedia annotations to accommodate different reading abilities, styles, and preferences [55].

6.1.6 Audio-Visual Resources Are Least Popular but Indispensable

While 3D models and VR scenes are most recognized and popular, video and audio are less engaging due to insufficient interaction control and time consumption. However, this doesn't mean systems should exclusively use 3D models/scenes. Information system design should follow "low cost, high efficiency" principles [56] while considering resource availability. 3D models and VR scenes are the most capital, labor, and technology-intensive resource types. From the above discussion, all six resource types offer different advantages and functions, and system design should maximize their combined effects: using text or patterns for easily understood content while emphasizing 3D models and VR scenes for abstract, difficult concepts.

6.1.7 Diverse Multimedia Resources Can Distract Reader Attention

Representative subjects like P58 noted that "with many selectable words and abundant related content behind each word, it's sometimes difficult to decide which to view," while P8 stated that "too much content makes it hard to focus on key information." This reveals that diversified multimedia resource annotation is a double-edged sword: successful combinations can focus attention on reading key points, reducing cognitive load and strengthening memory; otherwise, they can distract and divert attention, shifting reading focus toward browsing all annotations and resulting in inefficient full-text reading. This attention dispersion occurs because original reading text only engages a single linguistic channel, whereas rich multimedia annotations engage dual or multiple cognitive processing channels, making readers linger among abundant annotations and forget to return to original text.

6.1.8 Abstract Knowledge Concretization Creates Cognitive Limitations but Provides Reading Guidance

Representative subjects like P25 believed that "readers should be guided…they need some self-information processing space," while P36 noted that "each additional layer of transmission creates another opportunity for misinterpretation, and final understanding may not reflect original meaning." Although multimedia annotations make complex ancient book vocabulary intuitive and concrete, some readers feel this intuitive approach deprives them of information processing and imagination space. This 质疑 (zhiyi) reflects cognitive limitations from abstract content concretization. In fact, VR ancient book systems target non-specialist readers lacking professional knowledge and cultural background—readers who commonly face grammatical, professional knowledge, cultural barriers, and insufficient motivation. Concretizing difficult knowledge aims to solve these obstacles, facilitate continued reading, and generate reading satisfaction, thereby forming persistent reading habits. Thus, while abstract knowledge concretization has cognitive ethical issues, it provides strong introductory and guidance functions for readers lacking basic background knowledge.

6.2 Employing Cultural Tourism-Related Resource Annotations

6.2.1 Mitigating Socio-Cultural Background Barriers and Promoting Document Content Understanding

Subjects highly recognized that rich, detailed, and well-organized annotation information providing explanations about characters, institutions, locations, regulations, and material culture made ancient book reading easier and more enjoyable. Representative subjects like P38 noted that "annotation resources quickly help understand text content," while P60 believed annotations "make dull, difficult ancient books easier to understand and comprehend stories." Using concrete cultural tourism resources to reveal abstract, complex ancient book difficulties reduces reading content cognitive load and helps readers understand original texts.

6.2.2 Revealing Reading Difficulties and Expanding Cultural Knowledge

Subjects highly recognized that VR ancient book systems provided social-historical culture and ancient handicraft background information that solved cultural and professional knowledge barriers about social customs, laws, and regulations of the eras in which ancient books were written. Representative subject P63 noted "extensive extended content, rich and interesting," while P29 commented that "content is very rich with diverse explanations." This demonstrates that integrating library, museum, and archival collection resources with material and intangible cultural tourism heritage resources [58] can effectively reveal ancient books' cultural value.

6.2.3 Facilitating Content Consultation and Improving Reading Efficiency

Following annotation content relevance and availability, each knowledge element features rich, diverse cultural tourism resource annotations. Applying the spatial contiguity principle from multimedia instructional design, corresponding annotation information appears near knowledge elements, saving readers literature search time [59], as P21 stated: "Detailed annotations save me time searching for materials myself." P47 noted that "without the VR ancient book system, viewing ancient books would be more energy and time-consuming." According to learning motivation theory, efficient reading enables readers to gain more self-efficacy and satisfaction during reading, fostering persistent reading motivation [60].

6.2.4 Integrating Cultural Tourism Resources for Edutainment

Representative subject P19 commented that "ancient book models are superb—previously visiting museums showed little, but VR is both realistic and clear," while P36 noted that "models like 'wax lamp' and 'imperial edict' allow me to experience museum content without leaving home, and combined with ancient books provide direct imaginative immersion." This reflects that cultural tourism resource annotations not only reveal complex reading content but also provide opportunities to visit museum collections and cultural tourism sites, embodying the edutainment approach advocated under current cultural-tourism integration perspectives [61].

6.2.5 Information Overload Reduces Reading Efficiency

Representative subjects like P17 noted that "keywords have too many knowledge

points requiring extensive reading work," while P41 commented that "reading takes more time, with focus shifting to scene visits, so efficiency is not high." According to the limited capacity assumption, since individual channel capacity is finite, excessive information creates competition for the same channel capacity. People tend to allocate limited capacity to interesting content (e.g., prioritizing VR scene visits), leaving surplus resources unprocessed and causing information overload. In fact, cultural tourism resource annotations aim to help readers select the most helpful annotations for understanding original text, not to read all annotations. Too many options distract reader attention, shifting focus toward browsing all annotations and reducing full-text reading efficiency.

6.3 Decomposing Reading Tasks

6.3.1 Segmenting Ancient Book Content by Knowledge Elements Helps Timely Address Reading Difficulties, Reduce Frustration, and Sustain Reading Motivation

Representative subjects like P18 noted that "keyword annotations help timely understand and organize different knowledge," while P15 believed that "keyword text annotations effectively and timely solve reading obstacles (somewhat like barrier-free reading books)." Segmenting complex, lengthy content is a common principle in multimedia instructional design. Segmenting ancient book content by knowledge elements helps readers promptly view difficult vocabulary and underlying cultural connotations, allowing readers with insufficient background knowledge to control reading pace according to their cognitive abilities [50], thereby facilitating sentence, paragraph, and full-text comprehension. From learning motivation theory, readers who understand content and acquire knowledge [63-64] generate intellectual satisfaction and persistent reading motivation, while more questions create frustration and reading interruption [65].

6.3.2 Knowledge Element-Based Segmentation Reduces Reading Coherence

Representative subject P30 noted that "focus somewhat deviates from the article itself, lacking integrity—the original intention was to read the full article, but the final focus may become individual word explanations." Diverse, rich, and interesting multimedia resources cause readers to over-focus on knowledge element annotations. While this timely solves reading difficulties, it reduces ancient book reading coherence. The continuity principle in multimedia instructional design holds that any interesting but useless additional content hinders comprehension [66], thus knowledge element segmentation and content design require optimization.

6.3.3 Storyline-Based Segmentation Makes Ancient Book Reading More Coherent and Logical

Representative subjects like P42 commented that "regarding storylines, I really like the system's story map—it condenses numerous texts, making it convenient to 梳理 (shuli) story 脉络 (mailuo)," while P44 noted that "story maps and au-

dio explanations more effectively helped me clarify chronological order." This shows that coherent audio narration and clear graphical displays help subjects grasp overall document content, confirming the continuity principle in multimedia instructional design regarding cognitive overload and content segmentation [66].

As discussed above, vocabulary-based knowledge element annotation and storyline-based segmentation play important roles in ancient book reading: knowledge elements help timely solve readers' difficult points and sustain reading motivation, while storylines make reading more coherent and logical, serving as crucial methods for deep ancient book understanding. Both are complementary and indispensable.

6.4 Constructing Embodied Reading Scenes

6.4.1 Conducting Venue Reading to Obtain Situational Perceptual Experience

Readers can gain direct experience or explanatory experience through audio-visual forms by autonomously visiting, exploring, and manipulating objects in virtual venues [67]. Representative subjects like P28 noted that "you can immersively enter venues and interact with ancient people, as if truly arriving in ancient book scenes," while P33 commented that "scenes can be reproduced…observing entire processes up close enables intuitive understanding of operations." This reflects that subjects must adjust distances from scene elements, walk, navigate, and engage sensory systems to obtain direct learning-by-doing experience—manifestations of embodied cognitive experience characteristics.

6.4.2 Providing Conditions for Embodied Cognition

Representative subjects like P58 noted that scene settings "allow multi-angle observation and autonomous exploration to adapt to scenes," while P41 commented that "I really like the scenes inside, which enable visits and on-site observation of many scenes that text cannot describe." This shows that reasonable VR scene construction can provide immersive reading experiences integrating mind-body-environment [68-69], mobilizing subjective initiative and multiple sensory channels to form intuitive understanding of abstract content.

6.4.3 Enhancing Reading Motivation

Reading interest and habits constitute core forces of reading motivation [70]. Embodied scene design enhances ancient book reading 趣味性 (quweixing). Representative subjects like P11 noted that "3D models/scenes are very interesting, with many dynamic scenes," while P10 commented that "palace forbidden scenes are very novel," indicating that interesting and novel features characterize VR ancient books. Moreover, compared to traditional ancient book reading, scene design enhances readers' knowledge acquisition satisfaction and pleasure, as P19 stated: "Scenes are great, much more vivid than pictures," and P57 noted that "it provides lively craft manufacturing processes." The 趣味性 (quweixing), novelty, and pleasure brought to readers by VR scenes all contribute to forming

persistent ancient book reading motivation [60].

6.5 Autonomous Interaction Control Functions

6.5.1 Mobilizing Readers' Subjective Initiative in Cognitive Processing

Scholars like R. Mayer believe that personal interaction control over learning content can regulate attention, processing, and integration capabilities required for cognitive processes, enhancing learning effects [59,71]—a concept advocated in multimedia instructional design. Representative subject P52 noted that "3D models like 'Yang Guifei' and 'round fan' can be grabbed for viewing, feeling very real," while P37 commented that "walking through library doors and finding the ancient book reading room is interesting—this part of the experience feels very good." This reflects that interactive behaviors like grabbing, rotating, and walking play important roles in readers' cognitive processing.

6.5.2 Engaging Multiple Sensory Channels to Interact with VR Environment and Form Embodied Cognitive Experiences

Representative subject P36 noted that "VR environments allow people without comfortable reading conditions to immediately enjoy undisturbed, beautiful reading environments…antique environments greatly help immersion," while P30 commented that "in VR environments, you can experience specific ancient labor and tool creation processes." P37 added that "the 'exclamation mark (audio explanation)' annotations in scenes are also interesting, feeling like supplements to scene content that enhance understanding." This shows that reasonable scene settings can transport readers into specific reading contexts, providing direct learning-by-doing and explanatory experiences.

6.5.3 Enhancing Reading Motivation

Representative subjects like P15 noted that "3D objectification is very interesting…can be zoomed and rotated for observation from all angles, greatly changing traditional picture viewing experiences," while P40 commented that "the feeling of turning book pages is very good." This shows that autonomous interaction control helps leverage personal interests, obtain pleasurable reading experiences, and generate cognitive satisfaction [72].

6.5.4 Insufficient Reader VR Literacy Constrains Interaction Control Experience

Professional VR equipment has low penetration rates, and most readers lack VR media literacy, manifested in unfamiliarity with VR device operation and discomfort with VR environments (e.g., physiological and psychological discomfort). As subject P13 noted, "learning controller interaction requires time and guidance." Scholar Yu Xiucai points out that "media literacy primarily refers to the public's ability to access, understand, and use media and media information" [73], closely connected to information literacy [74]. Cultivating reader VR media literacy depends on VR equipment upgrades and popularization. Additionally, VR ancient book system design should adopt more natural and usable

interaction methods to enhance autonomous interaction experiences.

6.5.5 VR Equipment Quality Limits Interaction Control Experience
Current VR interaction devices suffer from low display resolution, heavy equipment, and inconvenient use. According to IDC's 2021 China AR/VR market predictions [75], "lightweight VR headset products will be more easily accepted by consumers in 2021, becoming market highlights," and "VR equipment price reductions will become a trend for VR all-in-one products in 2021, with pricing closer to consumer capacity." This suggests future improvements in VR equipment quality and comfort alongside price reductions will enhance reader VR media literacy and interaction control experiences.

Research demonstrates that the VR ancient book system significantly addresses content understanding, cultural barriers, and insufficient reading motivation, solving vocabulary barriers in language obstacles though character recognition and grammar issues require new design functions. Shortcomings include annotation information overload, non-intuitive interaction control, reading incoherence caused by excessive annotations, and distracted reading attention. The study validates the usefulness of system design principles and theoretical models in overcoming general readers' ancient book reading barriers, proposing VR ancient book system design methods theoretically and contributing creative VR ancient book applications practically. However, VR ancient book system design and practice should also avoid the series of usage problems identified in this design.

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Author Contributions

Zhang Ning: Proposed research design and model, conducted experiments, collected and analyzed data, wrote the paper.
Miguel Baptista Nunes: Guided research design, model construction, experimental process, and data collection and analysis.
Li Junyang: Provided technical support for experiment implementation and proofread the full paper.
Zhang Weibo: Provided technical support for experiment implementation.

Designing a Virtual Reality Chinese Ancient Book System for Reading and Culture Promotion: A Theoretical Model Development and Implementation

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Abstract: [Purpose/Significance] General readers encounter barriers in reading Chinese ancient books (CABs) caused by access restrictions, ancient Chinese comprehension difficulties, lack of professional knowledge, specific cultural backgrounds, and insufficient reading motivation. This research aims to use Virtual Reality (VR) technology to resolve (or mitigate) these barriers and promote CAB reading and cultural dissemination. [Method/Process] This research first analyzed theories in cognitive science and educational technology through literature review, then proposed VR CAB design principles and a theoretical model. A VR CAB prototype was developed and tested based on one case study through laboratory testing. A field experiment was undertaken to evaluate the VR CAB to prove the usefulness of design principles and theoretical model. [Result/Conclusion] The contributions of this research are: (1) design principles for VR CAB systems; (2) a theoretical model for VR CAB systems; (3) the first-ever prototype of a VR CAB system; and (4) a theory of using VR CAB design. These contributions are very helpful for both academic researchers wanting to enter this complex interdisciplinary field as well as industry practitioners wanting to apply these models on commercial applications.

Keywords: VR; virtual reality; Chinese ancient book; reading promotion; culture dissemination; embodied cognition

Note: Figure translations are in progress. See original paper for figures.