

An Experimental Study on Comprehension Performance and Immersive Experience in Digital versus Print Reading: The Case of Popular Science Knowledge (Postprint)

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Abstract

[Objective/Significance] By simulating real-world reading conditions and environments of paper-based and digital reading, this study observes and tests the differences in reading effectiveness between users' digital and paper reading processes, aiming to provide references for library reading services and reading resource development.

[Method/Process] Using medium-length popular science articles as examples, a controlled group experimental method is employed to compare the differences between paper reading and digital reading from the perspectives of reading comprehension and immersive experience.

[Results/Conclusion] When reading medium-length popular science articles, users demonstrate better comprehension effectiveness with paper reading than with digital reading; however, no significant difference exists between the two in terms of immersive reading experience. Users' immersive reading experience is associated with their educational background and personality. The development of library reading services and resource development should be advanced based on personalized reader analysis and services.

Full Text

Preamble

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An Experimental Study on Reading Comprehension Effects and Immersive Experience in Digital versus Paper Reading: Taking Popular Science Knowledge as an Example

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Abstract

[Purpose/Significance] This study simulates real-world reading situations and environments for both paper and digital reading to observe and test differences in reading effects between digital and paper reading processes, aiming to provide references for library reading services and resource construction. **[Method/Process]** Using medium-length popular science articles as examples, this study employs a controlled group experiment to compare differences between paper and digital reading from the perspectives of reading comprehension and immersive experience. **[Results/Conclusions]** When reading medium-length popular science articles, users demonstrate better comprehension with paper reading than with digital reading. However, no significant difference exists in immersive reading experience between the two modalities. Users' immersive reading experience correlates with education level and personality. Library reading services and resource construction should advance based on personalized analysis and services for readers.

Keywords: digital reading; paper reading; reading comprehension; immersive experience; reading service

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Reading constitutes an important pathway for acquiring knowledge. With the rapid development of modern technology, means of obtaining reading materials and information have become increasingly diverse, evolving from the traditional era of print media to today's digital media era of computer networks [1]. While maintaining conventional paper reading habits, new reading methods such as electronic reading, mobile reading, and online reading have emerged, becoming hot topics in academic research [2]. According to the latest 15th National Reading Survey released by the China Publishing Research Institute, the contact rate of digital reading methods among Chinese adult nationals has risen continuously, reaching 73.0% in 2017 [3], surpassing the reading rates for books, newspapers, and journals. In classroom teaching, the state vigorously promotes the integration of information technology with various subjects, making digital learning methods widely applied [4].

However, the fragmented and fast-paced nature of digital reading reduces opportunities for deep contemplation [7], and diminishes the edifying effects of paper reading with its scholarly, moral, emotional, and cultural influences on readers [8]. What, then, are the actual differences in reading effects when readers engage in paper versus digital reading in daily life, and which modality facilitates deeper engagement? This study examines differences in reading depth

between natural paper and digital reading conditions from the perspectives of comprehension effects and immersive experience, identifying factors that influence reading effectiveness to provide references for library reading services and resource construction.

1 Literature Review

WeChat and Weibo, as representative self-media platforms, have been extensively promoted and applied in reading promotion efforts at university libraries [5], indicating that digital reading has become a mainstream reading method in our lives, quietly changing our reading habits. Digital reading refers to the digitization of reading objects and methods, such as mobile reading, e-books, and web reading [6]. Compared with paper reading, digital reading accommodates the fast-paced lifestyle of contemporary society. Mobile terminals are unrestricted by time and space, offer strong interactivity with users, and help people quickly search for rich and vivid content during limited free time, providing great convenience and speed. However, domestic scholars point out that this fast-food, casual, and fragmented reading style lacks a reflective thinking process [7], and reduces the scholarly, moral, emotional, and cultural edification that paper reading provides [8].

Paper reading, as humanity's oldest reading method, represents a "deep reading" that digital reading cannot replace [9], prompting scholars both domestically and internationally to employ experimental and survey methods to compare the impacts of digital and paper reading from multiple perspectives including user preferences [10], carrier design [11], and mobile reading service quality [12], offering their own recommendations. Regarding comprehension effects, most studies have used controlled experiments to compare information cognition and memory. J. Stoop [13] and J. M. Noyes [14] found that paper groups demonstrated much better comprehension of complex information after reading academic literature, though some scholars found no comprehension differences between screen and paper reading. For instance, D. Daniel [15] tested students' performance with electronic textbooks under laboratory and home conditions and found no differences; S. Y. Sun [16] found no significant comprehension differences between paper and digital texts among middle-aged people aged 45-54; and J. Young [17] used newspaper articles to measure core information retrieval scores among college students and found no significant differences between paper and digital groups. Domestic scholars have also conducted experimental tests: Yuan Xilin [18], referencing PISA reading literacy assessment approaches, designed test questionnaires for 6,000-word novel materials and found slightly weaker cognitive processing effects for complex information in digital reading; Xu Junying [19] and Guo Lian [2] both found that mobile reading comprehension was superior to paper reading for short texts under 1,000 words.

Recently, scholars have proposed that deep understanding and thinking often occur during immersive reading [20], suggesting that research should include reading immersive experience, though comparative studies on immersion differ-

ences between paper and digital reading remain scarce. N. S. Baron [21] found in 2013 that undergraduates aged 18-24 preferred paper reading and believed it easier to become immersed in paper texts than in electronic reading. J. Hou [22] had readers use paper materials and iPads to read comics under three conditions and found no comprehension differences but better immersion effects with paper reading. Liu Kunfeng [23] used questionnaires to design reading experiments comparing digital and paper reading immersion, while Zhu Ming [24] interviewed 13 university library users and found immersive experiences 普遍存在 (ubiquitous) during reading. Zhang Bing [25] used eye-tracking technology and found that paper reading enabled greater focus.

Overall, previous reading comprehension experiments have yielded different conclusions, while immersion studies generally suggest paper reading is more immersive than digital reading. However, most experiments used digital reading carriers that mimicked paper books in screen size and content presentation, without considering the mobile reading devices and digital reading interfaces most commonly used in daily life, while also ignoring potential effects of immersion's intrinsic properties and reading environments. Furthermore, as research deepens, experimental analysis needs to be refined to specific text types. Previous studies mostly used long and short academic materials, news, novels, and comics to design comprehension and immersion experiments, without investigating medium-length popular science articles, which represent the typical length of current mobile digital reading content such as news. According to national reading surveys, Chinese adult nationals' mobile reading contact rate reaches 71.0%, with 63.4% having engaged in WeChat reading [3], indicating that mobile WeChat reading has become the primary form of digital reading. Therefore, this study selects mobile phones as the digital reading carrier and uses a WeChat article format as the digital reading interface to simulate natural reading environments, comparing comprehension effects and immersion differences between paper and digital reading of medium-length popular science articles under natural conditions.

2 Theoretical Basis

Immersive experience, proposed by M. Csikszentmihalyi in the 1960s, describes an emotional experience where individuals show strong interest in an activity or object and become completely absorbed [26]. When fully immersed, individuals subjectively experience enjoyment, relaxation, calmness, and harmony—a positive psychological experience [27]. Scholars worldwide have applied immersion to multiple fields including learning, gaming, education, sports, and online shopping. Immersive experience comprises nine dimensions: clear goals, enjoyment, challenge-skill balance, sense of control, concentration on tasks, clear feedback, action-awareness merging, time distortion, and loss of self-consciousness [28].

Ren Jun [29] summarized the conditions for immersion generation into three aspects: First, the activity must have structural characteristics, meaning participants know their goals and receive immediate feedback; second, perceived

challenges and skill levels must achieve relative balance—when challenges fall below skills, individuals feel bored, but when challenges exceed skills, individuals experience pressure leading to anxiety, so only balanced challenges and skills produce immersion; third, immersion depends on the subject’s own characteristics. K. Asakawa [30] believes that autotelic personalities—people with clear goals and motivations—are more likely to experience immersion, while F. Ullén [31] and D. Weibel [32] found that among the Big Five personality traits, conscientiousness, extraversion, and openness positively correlate with immersion, while neuroticism negatively correlates. Thus, personality characteristics significantly influence immersion states. Therefore, this experiment includes personality analysis to explore the relationship between reading immersion and personality.

3 Experimental Design and Control

3.1 Experimental Purpose

This experiment simulates real-world reading situations and environments for paper and digital reading to observe and test differences in comprehension effects and immersion levels between digital and paper reading processes.

3.2 Experimental Design

This study employs a controlled group experiment, using paper readers as the control group and digital readers as the experimental group. By controlling experimental materials, environment, and devices to mimic everyday reading conditions, both groups read identical content under the same experimental environment and complete questionnaires to compare reading comprehension effects and immersion, as well as explore the relationship between reading comprehension and immersion. The experiment incorporates experimental stimuli and personality tests during reading to detect whether environmental and individual factors affect immersion, with experimental stimuli serving as a simple and effective method to verify immersion levels measured by the immersion scale.

3.3 Participant Selection

Research shows that people born after 1980 are “digital natives” for whom the network is their living environment [33], and national reading surveys indicate that 60.7% of Chinese adult digital reading contactors are aged 18-39 [3], demonstrating that youth constitute the main body of digital reading. Since this experiment randomly divides participants into digital and paper reading groups, participants must possess both digital and paper reading habits and abilities. Therefore, this study selects “digital natives” aged 18-39 as the experimental subjects.

The experiment recruited volunteers aged 18-39 from campuses and society,

emphasizing participants' voluntary engagement. A total of 43 participants were recruited, meeting the requirement for two-group experiments. All participants had normal or corrected vision, native Chinese language proficiency, and average Chinese language grades. All owned mobile phones and were familiar with their use. To ensure age distribution uniformity, participants were randomly divided into two groups by birth decade (post-80s and post-90s), one reading paper materials and the other digital materials. Three participants omitted questionnaire items, resulting in three invalid datasets being removed, leaving 40 valid participants. Grouping results are shown in .

3.4 Test Material Selection

Reading test materials were sourced from the online article *"From the Global Panda Craze: A Scientific Explanation of the Meaning of 'Cute'"*. Popular science articles were selected because LinkApp Big Data monitoring revealed that post-80s readers prefer science, literature, and education books, while post-90s readers prefer science, fantasy, and literature [34], making such articles common reading content for participants with moderate difficulty and sufficient knowledge content to facilitate immersion.

Surveys show most people's daily digital reading time does not exceed one hour, while average single-session reading duration on mobile reading apps is 21 minutes, indicating digital reading content tends to be short [35]. Therefore, this experiment controls text length at 3,000-4,000 characters, ensuring neither excessively short nor long articles while keeping information within acceptable ranges. Average adult reading speed is approximately 200-300 characters per minute, resulting in reading durations of about 10-20 minutes [36].

3.5 Experimental Carrier

Digital reading materials are presented via a WeChat public account format on mobile phones, mimicking existing article layouts with various static and dynamic images as auxiliary or interfering factors commonly encountered in digital reading. Paper reading materials are printed on A5 paper with size 10 Song font, without surrounding distractions, using manual page-turning to simulate real paper reading conditions.

3.6 Experimental Stimuli and Control

The experiment simulates real-world reading environmental interference through conversation sounds outside the classroom. Conversation sounds were selected because they are common in daily life, not overly sharp enough to awaken deeply immersed participants, yet contain content that can attract participants with shallow or no immersion. To prevent interference from factors other than experimental stimuli, the experiment is conducted in a quiet classroom. Surveys indicate users' most concentrated reading time is before bedtime [37], so this experiment is scheduled for 7 PM. To prevent

psychological expectations about results and procedures, participants are not informed of the experimental purpose and specific content beforehand.

3.7 Questionnaire Design

The personality test uses the Chinese version of NEO-FFI. The NEO Personality Inventory, developed by American psychologists Costa and McCrae based on the Big Five personality theory [38], is a widely used personality assessment scale worldwide [39]. The NEO-FFI simplified version comprises 60 items measuring openness, conscientiousness, extraversion, agreeableness, and neuroticism.

The reading comprehension questionnaire is based on the PISA (Programme for International Student Assessment) framework, which assesses reading literacy, mathematical literacy, and scientific literacy [40]. Referencing PISA reading literacy assessment approaches, five questions were designed to evaluate comprehension from three aspects: information retrieval (questions 1-2), integrated interpretation (questions 3-4), and reflection/evaluation (question 5) [41]. All items are multiple-choice, scored as 1 for correct and 0 for incorrect, with a total possible score of 5. After initial design, six graduate students completed pilot testing, and items were adjusted based on results to ensure normal score distribution.

Reading immersion scale items are adapted from Ye Jinhui's *Adolescent Learning Immersion Experience Questionnaire* [42], which demonstrates Cronbach's $\alpha > 0.8$ with good internal consistency and high reliability and validity. Since only learning-specific terms were replaced with reading-related terminology and some items were deleted without adding new ones, the reading immersion scale maintains equivalent reliability and consistency. The scale measures seven dimensions: challenge-skill balance, action-awareness merging, goals and feedback, concentration, loss of self-consciousness, sense of control, and enjoyment experience, using a 5-point Likert scale from "very uncharacteristic" to "very characteristic." Dimension explanations are provided in . The questionnaire also includes an item about experimental stimulus interference: "Did conversation sounds occur outside the classroom during the experiment?" with yes/no responses scored as 1 and 2 respectively.

3.8 Experimental Procedure

To minimize time pressure effects, participants are not timed during reading but record their reading duration afterward. Before the experiment, participants complete the Big Five personality inventory within 10 minutes under guidance, then rest for 10 minutes before the formal experiment begins. The experimental flow is shown in [Figure 1: see original paper].

Both groups begin reading simultaneously. During reading, the experimenter creates conversation sounds outside the classroom. Considering some participants may not quickly achieve immersion or may read faster than normal, experimental stimuli are introduced approximately three minutes after reading

begins, with conversation duration controlled within 15 seconds. After completing the article, participants answer comprehension questions and complete the immersion scale.

4 Research Results

To examine basic conditions of comprehension and immersion between paper and digital groups, we first calculated means and standard deviations for 40 participants and compared between-group differences, with results shown in and .

shows that the paper group achieved higher average comprehension scores than the digital group (4.500 vs. 3.750), with t-test results indicating significant between-group differences in total comprehension scores. shows the paper group also scored higher on total immersion (109.80 vs. 106.40), but t-tests revealed no significant between-group differences in immersion scores, suggesting similar immersion levels for medium-length popular science articles across reading modalities.

To further investigate factors correlating with comprehension and immersion, correlation analyses were conducted. Results in show that for this popular science article, comprehension effects correlate with reading carrier, while immersive experience correlates with education level, openness personality, and experimental stimuli.

4.1 Relationship Between Comprehension Effects and Various Factors

Correlation relationships between comprehension effects and various factors are shown in . Total comprehension scores negatively correlate with reading carrier ($r = -0.540$, $p = 0.001$), indicating higher comprehension scores in the paper group. At the dimensional level, “integrated interpretation” negatively correlates with reading carrier ($r = -0.546$, $p = 0.000$), showing better text interpretation in the paper group. “Reflection and evaluation” positively correlates with time ($r = 0.370$, $p = 0.019$), indicating deeper understanding with longer reading duration.

4.2 Relationship Between Immersive Experience and Various Factors

Correlation relationships between immersive experience and various factors are shown in . Total immersion scores positively correlate with education level ($r = 0.380$), openness personality ($r = 0.349$), and experimental stimuli ($r = 0.369$), all $p < 0.05$, suggesting higher immersion among more educated or more open individuals, and that those who did not hear conversation sounds were more immersed. At the dimensional level, “challenge-skill balance” negatively correlates with neuroticism ($r = -0.323$, $p = 0.042$), indicating that higher neuroticism reduces acceptance of challenging tasks. “Action-awareness merging” positively correlates with education level, openness, and agreeableness, and negatively cor-

relates with neuroticism, suggesting that more educated, open, and agreeable individuals more readily merge thought and action, while neurotic individuals show the opposite pattern. “Goals and feedback” positively correlates with education level and openness ($r = 0.350$ and 0.411 respectively, both $p < 0.05$), indicating that more educated and open individuals more actively seek reading goals and obtain timely feedback. “Concentration” positively correlates with education level and experimental stimuli ($r = 0.418$ and 0.313 respectively, both $p < 0.05$), showing that more educated and focused individuals concentrate better during reading. “Sense of control” positively correlates with experimental stimuli ($r = 0.333$, $p = 0.036$), suggesting that individuals who can control their reading state are less likely to hear external sounds. “Enjoyment experience” positively correlates with openness ($r = 0.434$, $p = 0.005$), indicating that more open personalities enjoy reading more.

4.3 Relationship Between Comprehension Effects and Immersive Experience

Correlation relationships between comprehension effects and immersive experience are shown in . Total comprehension scores do not correlate with total immersion scores. However, at the dimensional level, total comprehension positively correlates with “action-awareness merging” ($r = 0.385$, $p = 0.014$), suggesting that greater integration of action and awareness facilitates better text comprehension. “Information retrieval” positively correlates with “goals and feedback” and “enjoyment experience,” indicating that individuals with clear reading goals and enjoyment more easily identify key information.

5 Discussion

5.1 Interpretation of Comprehension Effects Results

This study found that paper reading produced better comprehension than digital reading for medium-length popular science articles. In contemporary society, most people browse WeChat Moments and public account articles during leisure time, reading quickly with short durations and fragmented time slots. Since WeChat articles can be saved and bookmarked, readers rarely actively comprehend and memorize content, often resulting in rapid, superficial reading [4]. Additionally, mobile phones’ small screens concentrate vision, causing eye fatigue during prolonged reading and affecting reading depth. Popular science articles, unlike easily understood novels and short news, require continuous reflection. Examination of collected paper materials revealed many participants marked and underlined articles, enhancing retrieval and understanding of key information—practices difficult to implement on mobile screens. The cognitive map mechanism [22] may explain this phenomenon: paper materials’ fixed page numbers and four corners help form spatial memory of text locations, enabling quick recall of key information when answering comprehension questions. Mobile scrolling and interspersed images weaken spatial cues and distract attention

and memory, increasing cognitive load. Therefore, paper facilitates formation of a complete cognitive map for more effective comprehension.

Generally, longer reading time correlates with deeper comprehension, but correlation tests showed no relationship between total comprehension scores and time. Many digital group participants completed reading in 4-5 minutes with decent scores, a phenomenon rarely observed in the paper group. The negative correlation between reading carrier and time also indicates shorter digital reading durations. This aligns with Yuan Xilin's discussion of how long-term digital reading behavior transforms the "reading brain," training non-linear collaborative thinking, enhancing mental agility, and prompting rapid content analysis and decision-making about information retention. In contrast, paper reading habits involve line-by-line reading [43], so faster digital reading does not necessarily indicate poorer comprehension.

5.2 Interpretation of Immersive Experience Results

Immersive reading involves continuous contemplation and even "self-loss," completely intoxicated by the textual world [20]. Immersed readers typically ignore environmental surroundings. The positive correlation between total immersion and experimental stimuli validates the adapted immersion scale's reasonableness. Inter-dimensional correlations and correlations with total immersion scores demonstrate the scale's consistency and measurability.

"Action-awareness merging," "concentration," and total immersion positively correlate with education level, suggesting that more educated individuals concentrate better and achieve higher immersion. This may stem from greater academic achievements and more developed reading skills enabling full engagement. However, this study found no correlation between reading carrier and immersion for 3,000-4,000 character popular science articles, indicating no significant immersion differences between paper and mobile screens under natural reading conditions. Factors beyond reading carrier likely affect immersion, including personality, reading habits, and content. Most participants exhibited openness and conscientiousness, with few showing neurotic tendencies, so no participants experienced extreme difficulty achieving immersion. Moreover, digital devices enable reading anywhere, and many have developed the ability to immerse despite noisy environments. Regarding content, mobile reading services are primarily content-driven [45], and participants' interest in popular science articles facilitated immersion across both carriers. Static and dynamic images in WeChat materials, compared to monotonous paper text, enhanced visual sensory experience and interaction, helping sustain attention.

5.3 Interpretation of the Relationship Between Comprehension and Immersion

Immersive reading often accompanies deep understanding and thinking. Our results show correlations between some immersion and comprehension dimensions

(see). Information retrieval ability represents a potential capacity to acquire, process, and transmit information. Individuals with accurate self-assessment of reading needs can better capture valuable information from complex, disordered environments [46]. Those who think less about their actions during reading focus more on textual content, deepening comprehension. However, the absence of correlation between total comprehension and total immersion scores suggests diverse factors influence comprehension, including reading methods, habits, content, and especially readers' own abilities and comprehension skills. Text comprehension involves rich, complex cognitive processing including visual perception, attention, memory, imagination, and reasoning—an integrative process built upon word and sentence processing [47]. Participants' reading abilities varied significantly, with education levels ranging from high school to doctoral degrees and ages from 18-38, creating substantial differences in knowledge accumulation. Many participants may have been highly immersed yet misinterpreted certain vocabulary or sentences, leading to incorrect answers.

6 Conclusions and Recommendations

This study found that under natural reading conditions, users demonstrate better comprehension with paper reading than digital reading for medium-length popular science articles, but show no significant difference in immersive experience. Reading immersion correlates with education level and personality. Based on these findings, we propose recommendations for libraries, publishers, and digital reading platforms:

1. **Select dissemination channels based on content attributes.** For short articles requiring timeliness but not deep comprehension—such as leisure entertainment and real-time news—digital resources are appropriate. For medium-to-long articles requiring intensive study, such as academic papers and popular science knowledge, paper books remain preferable.
2. **Enhance cognitive experience through paper material design.** Book designers can innovate with paper texture, color, scent, and typography to enhance sensory and cognitive experiences, guiding readers to enjoy reading states and become truly engrossed in texts.
3. **Leverage digital media for reading promotion.** In the digital reading era, libraries should fully utilize digital media to mobilize reading enthusiasm: excerpting interesting, moderate-length chapters from paper books for dissemination via WeChat public accounts, Weibo, and mobile libraries to broaden reach and stimulate reading and purchase desires; leveraging digital media interactivity to recommend suitable reading content and methods based on users' education, personality, and reading abilities; establishing audio-visual rooms to present book content through video or audio, helping readers less prone to immersion engage with texts through alternative modalities.

Additionally, readers should proactively select and adapt reading methods according to their circumstances to achieve optimal reading states.

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Zhang Guangyuan: Responsible for experimental design and implementation, paper writing and revision

Xu Xiaochen: Revised key sections of the paper

Pu Hongyu: Collected literature and translated English content

Experimental Study of Reading Comprehension Effects and Immersive Experience on Paper Reading and Digital Reading—Taking Sci-

ence Knowledge as an Example

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Abstract: [Purpose/significance] This paper simulates the reading situation and environment of paper reading and digital reading in reality to observe and test the difference of reading effect between digital reading and paper reading, in order to provide reference for library reading service and reading resource construction. [Method/process] This study uses the middle-length popular science article as an example, adopts the control group experiment method to compare the differences between paper reading and digital reading from the perspective of reading comprehension and immersion experience. [Result/conclusion] Users' reading comprehension effect of paper reading is better than that of digital reading when reading middle-length popular science articles, but there is no significant difference in reading immersive experience. Users' reading immersive experience is related to education and personality. The library's reading service and resource construction should be based on the reader's personalized analysis and service.

Keywords: digital reading; paper reading; reading comprehension; immersion experience; reading service

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

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