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Research on the Design of Virtual Reality Online Education Information Presentation Based on Multi-Sensory Cognition

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Abstract: The popularity of the online teaching model increased during the COVID-19, and virtual reality online education is now firmly established as a future trend in educational growth. Human–computer interaction and collaboration between virtual models and physical entities, as well as virtual multi-sensory cognition, have become the focus of research in the field of online education. In this paper, we analyze the mapping form of teaching information and cue information on users' cognition through an experimental system and investigate the effects of the presentation form of online virtual teaching information, the length of the material, users' memory of the information, and the presentation form of information cues on users' cognitive performance. The experimental results show that different instructional information and cue presentation designs have significant effects on users' learning performance, with relatively longer instructional content being more effective and users being more likely to mechanically remember the learning materials. By studying the impact of multi-sensory information presentation on users' cognition, the output design of instructional information can be optimized, cognitive resources can be reasonably allocated, and learning effectiveness can be ensured, which is of great significance for virtual education research in digital twins.

Keywords: multi-sensory HCI; online education; information presentation; virtual reality

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1. Introduction

Nowadays, individual knowledge labor is increasingly replacing physical labor, industrial products and services are transitioning from material- and labor-based to knowledge-based, and the conventional educational paradigm is progressively failing to meet society's demand for educational resources. Online education using virtual reality has become popular. Virtual reality online education is a comprehensive combination of information technology and educational resources that raises the standard of instruction while broadening its reach and shattering barriers imposed by the conventional education sector. Online education is being optimized as a result of the ongoing advancements in information technology, and the educational model is no longer restricted to the distribution of information but has expanded to include a variety of presentation formats and carriers, leading to the creation of a significant amount of digital educational resources. Among them, the idea of the Digital Twin University, for instance, is used to create a perpetually online, open sharing, and sustainable education platform in virtual space by combining digital twin, artificial intelligence, and blockchain technologies to organize educational content before disseminating it to improve educational outcomes [1].

Building virtual "classrooms" in the information system using specific information technology tools is what the Digital Twin University's virtual reality education program entails. The ability for teachers and students to connect to the platform for online communication and course learning can be seen as transforming the traditional classroom into a virtual setting, eliminating physical space restrictions, and improving student learning. The cognitive load of users in connection to multi-sensory engagement in online learning in virtual reality has not received much attention. In order to improve the output design of instructional material, the purpose of this paper is to examine the effects of multi-sensory information presentation on user cognition.

From the standpoint of the user's cognitive burden, exploring multi-sensory interaction in virtual reality for online education is crucial for two primary reasons. On the one hand, virtual reality has a lot to offer the online world. Virtual reality technology and education are combined in a student-centered approach to teaching, which not only broadens the horizons of teachers and students and greatly increases the teaching area, but also enables a large growth of teaching resources. Virtual learning, in essence, overcomes the spatial and temporal constraints of traditional learning by simulating real-world events in order to make up for the absence of context provided by professors. On the other hand, including multiple sensory is very beneficial when it comes to online education. According to Matsubara's research [2], the visual sense is the most popular and efficient way for users to get information, and it accounts for the majority of the knowledge that humans acquire. Information in a number of forms, including color, shape, state, light, and shadow, are received through the visual senses. Yet, the challenges of limited cognitive information reception, limited perceptual range, visual information overload, and limited information coverage in a single visual sense make the reception of more sophisticated information susceptible to these issues. Up to a point, effective multi-sensory interaction can boost learning effectiveness.

Education departments all over the world are concentrating on the potential of virtual reality in education and are anxious for its advantages to be shown in practice in a concrete way as virtual reality technology continues to advance. The majority of researchers have steadily concentrated on developing virtual reality environments for instruction and learning. Ashoori et al. [3] suggested that instructional Agents could be used in a multi-user virtual reality environment to personalize its representation to meet the needs of different students. Hu and Lee [4] found that virtual reality can play a unique role in addressing existing educational challenges through immersive, hands-on learning, such as deepening the relevance of learning content to students' lives and aiding the learning of abstract skills such as empathy, systems thinking, and creativity. Henry [5] showed that understanding students' expectations of online education and creating a student-centered online education system can help improve student satisfaction and learning outcomes. Ding et al. [6] conducted negotiation training in virtual reality in an experiment that gave users virtual cognitive abilities as well as an immersive experience, and the results showed that negotiation training in virtual reality can improve people's negotiation knowledge and self-efficacy and has some impact. Bertram et al. [7] compared the results of training police officers in a virtual environment with those in a realistic scenario and found that the knowledge and skills acquired by police officers in the virtual simulation scenarios were transferred to the real scenario applications with the same results as the traditional live training. Merchant et al. [8] built three virtual learning scenarios in Second Life for students to learn chemical concepts. In these virtual environments, students can use interactive devices such as a mouse and keyboard to flip the chemical molecules in the virtual reality environment to observe the molecular structures and achieve a better understanding of the molecular structure models. Le et al. [9] established a construction safety training system by providing visual information, easy communication, flexible interactive spaces, and a social VR-based immersive environment for construction safety education, so that learners can not only understand the profound causes of accidents and hazard prevention methods but also identify potential safety risks in the safe construction process, thus reducing accidents on site. Wang [10] based his work on constructivism, virtual reality technology immersion, and other theories for model construction, and guided the design and development of virtual reality educational applications by analyzing students' learning situations and the role of virtual reality in the scenarios, and realized virtual reality-supported educational applications for junior high school physics subjects. However, Parong and Mayer [11] demonstrated through their study that students who experience immersive virtual reality courses have a certain degree of distraction and generate high levels of emotional and cognitive interference, resulting in poorer learning outcomes compared to students who view slideshow courses. Thus, new applications can be explored by taking advantage of virtual reality as opposed to completely replicating traditional courses.

The current virtual reality online education platform is primarily positioned as an experiential platform. It creates a virtual platform using sensory simulation tools and dynamic models of virtual environments, allowing users to directly interact with their senses and experience immersive teaching. Virtual reality online education is more diverse than traditional offline teaching since it incorporates the advantages of both online and offline learning environments. There is also a more adaptable and laid-back learning environment for students [12].

However, many current studies have shown a significant relationship between the effectiveness of online education and the cognitive load of users. For example, Bachen et al. [13] demonstrated that cognitive load is the key to changing the relationship between presence and learning outcomes and that appropriate cognitive load intensity can promote learning effectiveness, while a too high or too low cognitive load intensity tends to produce negative effects. For the study of cognitive load in virtual reality, Sun Hui et al. [14] proposed a distributed cognitive-based resource model for the problems of increased user cognitive load and uneven distribution of cognitive resources in virtual contexts, constructed information structures, and interaction strategies according to the resource model, and applied the model to the View-VR system, thus reducing the user's cognitive load and improving the user experience. Andersen and Makransky [15] divided the external load (EL) dimension into three sub-scales related to the virtual learning environment (VLE) by studying the validity and reliability of the Leppink cognitive load scale (CLS), using the partial credit model (PCM), confirmatory factor analysis (CFA), and correlation with retention tests to demonstrate the validity of these measures. Ji Tianqi [16] implemented multi-sensory interaction based on two interacting senses, eye movement and gesture, using parallel and complementary primary and secondary senses and a task-based multi-sensory fusion strategy, and obtained the most appropriate multi-sensory interaction through an experimental study. Pitts et al. [17] found that redundant visual–auditory and visual–haptic dual-sensory stimuli reduced response times compared to visual stimuli alone, a phenomenon known as the redundant target effect (RTE). Xu Fenfen [18] demonstrated the role of avoiding information presentation redundancy and balancing the two pathways for cognitive load during instruction by studying, for example, the reuse of visual sensory text and speech content tends to cause information presentation redundancy, while processing schema and text can be more loaded, so text can be presented again after the end of speech to reduce information presentation redundancy. Their existing research can be summarized to obtain the theoretical research model related to virtual reality online education as shown in Figure 1.

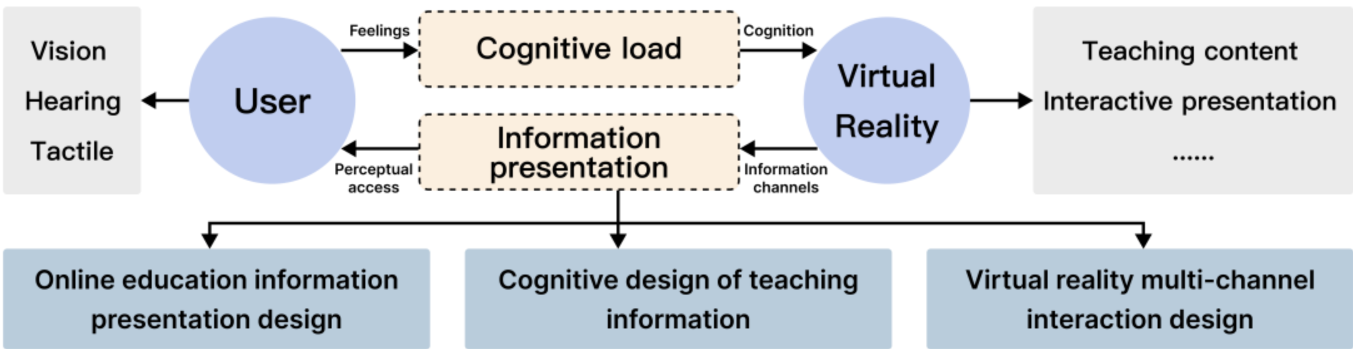


Figure 1. Theoretical research models related to virtual reality online education.

In conclusion, optimal cognitive load can significantly enhance users' learning outcomes in online virtual reality instruction. To this end, the focus should be on users' cognitive architecture; parallel design of main and auxiliary sensory from two dimensions (visual and auditory); learning materials, media tools, and teaching organization forms used in the teaching process; and proposing specific design methods in a targeted way to create a highly efficient teaching mode and optimize learners' knowledge construction. In order to investigate the effects of online educational information presentation design in virtual reality on user cognitive performance, this paper focuses on multi-sensory user cognition. To confirm the significance of the effects of each factor on cognitive performance, an experimental study of instructional information cognition in a virtual reality environment was conducted.

2. Materials and Methods

Virtual reality online learning blends some of the benefits of classic offline learning models with current online learning platforms on mobile devices and PCs (such as those provided by ROOM software), but it has substantial drawbacks in terms of the period of time it takes to study. It might be claimed that the virtual reality setting puts users under more physical and mental strain, and that more efficient teaching techniques are required to make up for the drawbacks brought on by learning's time limits [19]. Higher standards for virtual instructional design are now necessary in order to help users use cognitive resources more wisely and reduce the severity of unneeded cognitive load. Table 1 summarizes a comparison of the traits of several educational models.

Table 1. Summary of the comparison of the characteristics of different educational models.

	Virtual Reality Online Teaching	Traditional Offline Teaching	Mobile and PC-Based Online Teaching
Teachingmode	Image, text, and audio lectures	Audio-based lectures, supplemented by text	Image, text, and audio lectures
Teachinginformation	Can be presented repeatedly, but content is binding	Non-representable and expandable	Can be presented repeatedly, but content is binding
Teachingfeedback	Delayed feedback on teaching Lack of discussion during feedback Feedback records can be kept for a long time	Provides timely feedback on issues Feedback can be given through discussion Difficult to keep feedback for a long time	Delayed feedback on teachingLack of discussion during feedback Feedback records can be kept for a long time
Teacher presence	Low presence	Strong presence	Low presence
Online communication	Text and verbal communication are both possible	Mainly verbal communication	Text-based communication
Communication participation	Equal atmosphere for communication and discussion Listen naturally, without participation Possibility to think for a long time Average communication efficiency Able to observe classmates' participation status	Discussion atmosphere is easily influenced by individuals It is easy to feel isolated without participating in the discussion Less time for reflectionCommunication is direct and effective Every move can be noticed	Equal atmosphere for communication and discussion Listen naturally, without participation Possibility to think for a long time Ineffective communication, with serious time delays Difficult to understand the participation status of classmates
Teaching environment	Immersive learning with relative concentration	Immersive learning with relative concentration	Easily disturbed by other external information
Teachinglocation	Flexible location with certain range requirements	Fixed position	Flexible location and no obvious range requirements
Teaching hours	Short, continuous study requires a lot of rest time	Long, but requires some rest time	Long and does not require regular breaks
User comfort	Pressure on the face, continuous use will produce dizziness	No significant effect	No significant effect

The interface between the user and the information interaction, as well as the process of obtaining and entering virtual information, are the key sources of cognitive burden in user learning. There are three primary considerations about the interaction features of virtual reality online education [20]:

- Spatial dimension interaction features;
- Sensory-aware interaction features;
- Operational dimension interaction features.

By establishing the required lighting, building, and object simulation components and simulating how they would function in the actual world, virtual reality converts the two-dimensional teaching interface into a three-dimensional one. The impact of each component on the user's behavior and perception must be taken into account in addition to the two-dimensional interface design from a three-dimensional standpoint. Virtual reality can create a variety of input methods through different senses of hand grips, and can even directly recognize gestures and get natural feedback from multiple sensory such as visual, auditory, and even tactile senses. This is in contrast to the information interaction sensory (mouse, keyboard, etc.) in cell phones or PCs.

2.1. Virtual Reality Online Education Multi-Sensory Cognitive Mechanism

With the development of multi-sensory interactive cognition, virtual reality technology will make use of a variety of sensory organs in the human body to construct the user's input to the virtual world simulation in a way that uses senses like the eyes, ears, and skin to receive a variety of external stimuli and permits predictable information output design, whose predictability is derived from the body's self-protection mechanisms and from acquired learning experiences [21].

A single sensory modality is obviously unable to meet the user's needs for receiving complete multidimensional information, as evidenced by the comparison of the information perception characteristics of various perceptual sensory shown in Table 2, which combines the findings from previous studies. If properly constructed, a multi-sensory interactive online education system can transfer information more effectively.

Table 2. Comparison table of information perception characteristics of visual, auditory, and tactile sensory inputs.

Characteristics	Vision Sensory	Auditory Sensory	Tactile Sensory
Expression dimension diversity	Extremely high	General	Singular
Reaction time of attention	Relatively slow	Rapid	Extremely responsive
Time change sensitivity	Insensitive	High sensitivity	Low sensitivity
Perceived range size	Limited range, strongly related to visual field range	360° omnidirectional spatial perception	Limited range, strongly related to visual field range
Expression of emotional changes	Difficult to express emotional changes	Easy to express emotional changes	Inability to express emotional changes
Spatial positioning accuracy	High accuracy	Low accuracy	Low accuracy
Multiple concurrent interference intensity	Weak interference	Strong interference	Strong interference
Environmental relevance	Weak correlation	Strong correlation	Weak correlation

In the field of cognitive scientific research, scholars generally consider visual perception as the dominant perceptual sensory modality, which is independent of non-visual information from other senses, and even the cognitive processing within the visual sense is highly independent and involves separate brain mechanisms [22]. On the other hand, the auditory sensory modality, which is the second most used sense through which humans receive information, can be split into speech and non-speech presentation types. Because auditory information can be processed separately, visual sensing varies from the cognitive-perceptual module of the auditory sensing. The user's information reception is not only slower and less accurate when there is only one auditory source available, but it is also more vulnerable to ambient factors that can hide their effects. In addition, individuals can only faintly detect the source of sound transmission in real life as a single sound source can be converted into a stereo sound by the refraction of the environment. In virtual reality, the use of 3D stereo sound can imitate this sound refraction as if the sound source were actually heard, enhancing immersion in the virtual environment [23].

Information in virtual reality environments is primarily delivered to users in the form of text, images, and audio, which are received by the users' visual and auditory senses which then results in perception, filtering of information, and allocation of cognitive resources. This is shown in the information processing model of humans and virtual reality environments in Figure 2. The quality and effectiveness of the information users obtain will vary depending on how it is presented, impacting how cognitive resources are allocated and resulting in varying degrees of cognitive burden. Hence, by avoiding cognitive overload that leads to insufficient cognitive resources, an appropriate allocation of users' cognitive resources through certain design methods can aid in improving learning efficacy.

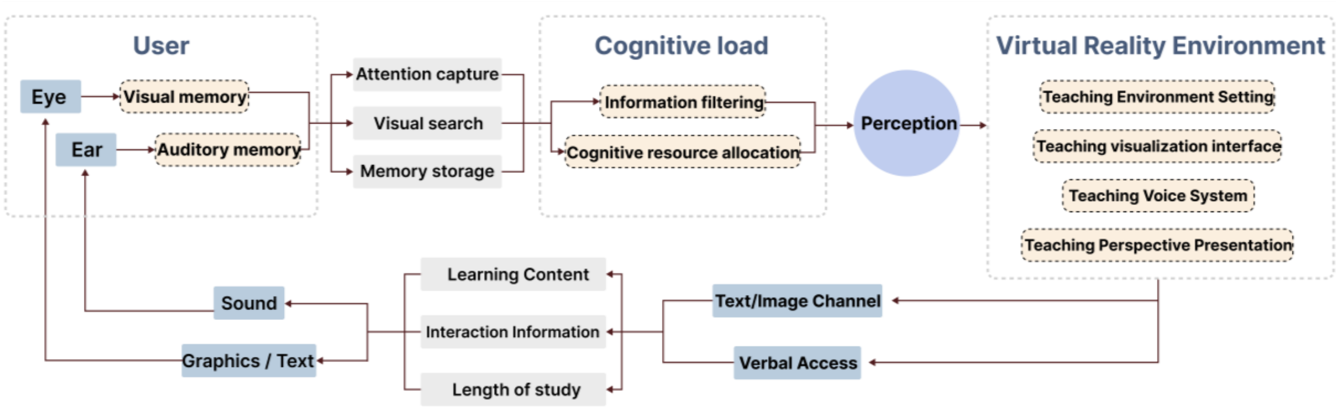


Figure 2. Teaching information processing model of user and virtual reality environment (HCI).

2.2. Purpose of the Study

Alkhattabi [24] discovered that coping with the generation of digital natives presents difficulties for higher education institutions. There is an increasing need to implement a learning management system that satisfies student aspirations due to the expansion of online learning resources and the rapid development of information technology and the Internet. Figure 3 illustrates the instructional material that influences users' cognition when learning online in virtual reality. The information is presented in two ways: visually and audibly. While examining the effect of cognizability on user learning effectiveness, the presentation of instructional content is frequently brought up. Information occurs in various forms, and the presenting form of instructional information affects the objective circumstance or stimulus pattern of humans facing instructional information. According to the sensory effect concept, some instructional materials can be best learned using a single sensory modality, while other materials can be best learned by utilizing many sensory channels that are superimposed.

Additionally, because of the real-time interactivity of online learning, the interface information is no longer restricted to teaching information, and the alert when new messages arrive may have an impact on students' learning states and, to some extent, how they allocate their cognitive resources. Students' perceptions vary, and different sensory channels acquire information with varying degrees of influence on cognition. In order to activate the human senses for cognitive purposes, new information is typically presented primarily through the visual and auditory senses, including color, motor status, ear markers, and auditory markers. Hence, in order to ensure that pupils are in the best possible condition, it is essential to design a suitable form of textual information presentation for the proper perceptual organ at the appropriate moment.

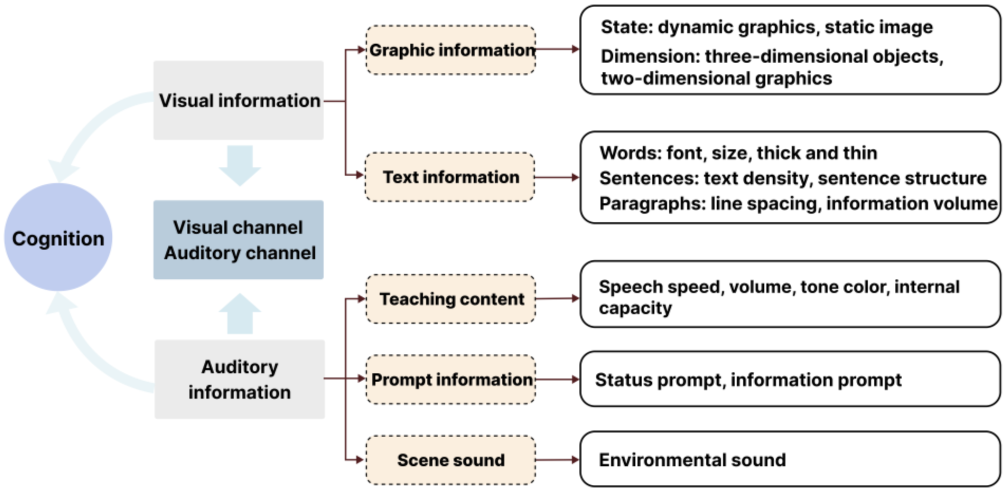
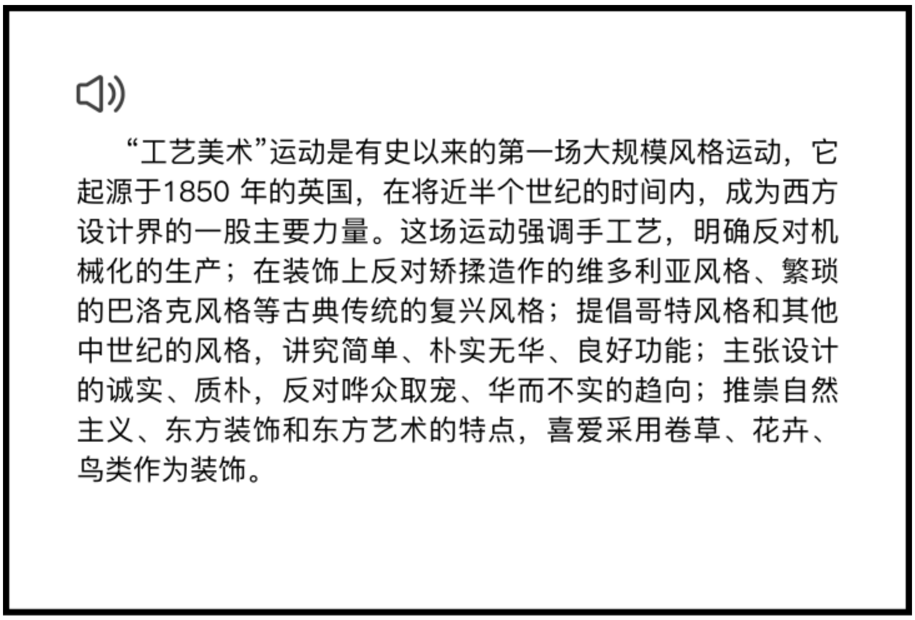


Figure 3. Summary of instructional information affecting users' cognitive load intensity in virtual reality online education.

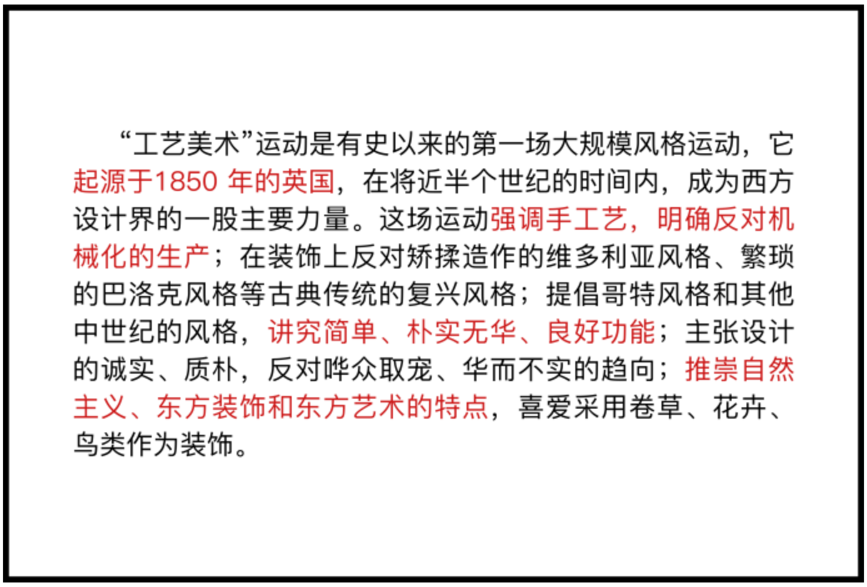
2.3. Experiment Preparation

According to an analysis of information presentation formats used in various online learning environments, textual content is typically presented using full text + audio, full text + key markers, and some textual information (key markers) + audio. The exact presentation format is depicted in Figure 4, using the content of Material 1 as an example. Details can be found in Appendix A (key markers in the materials are underlined in the English translation). This experiment examines how these three presentation types are actually used.

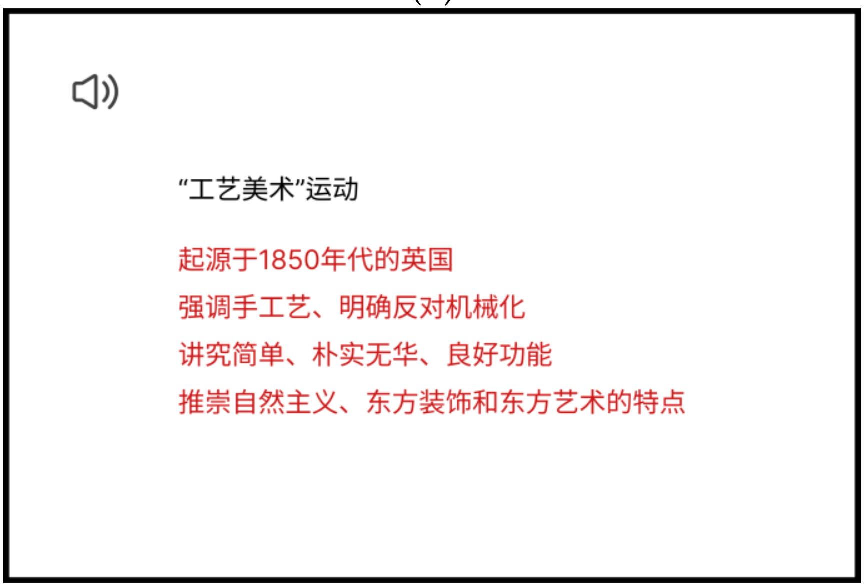


(**a**)

Figure 4. *Cont.*



(**b**)



(**c**)

Figure 4. Full text + audio (**a**), full text + key markers (**b**), and some textual information (key markers) + audio (**c**). (Full text: only text information is displayed; audio: information related to content; key markers: marking of key information in the article).

According to user research, the length of textual contents also has an impact on how well users will take in the information. Longer information tends to make the cognitive load too high, leading to cognitive stress, whereas shorter information frequently fails to generate an appropriate cognitive burden for users, wasting cognitive resources. In order to better understand how users process information in different formats, this study splits the experimental materials into two categories: lengthy texts (more than 400 words) and short texts (200–400 words).

Different perceptual sensory have varying degrees of information perception and interference with learning content when it comes to the display of information cues in online education. This study uses visual, visual + auditory, and auditory information cues to perform experimental research to examine the impact on users' cognition.

2.4. Participants

A total of 33 users (male/female = 11:22) with normal physical and psychological functioning volunteered to take part in this study. They were between the ages of 17 and 20. All individuals were free of conditions like color blindness and had normal or corrected visual acuities of at least 1.0. In order to participate in the experiment, participants had to fill out a registration form that included their name, gender, age, grade level, and visual acuity. Students were instructed to become familiar with the complete experimental process as well as the technical terminology of the non-teaching content involved because the experimental teaching topic was beyond their knowledge blindness.

2.5. Experimental Environment and Equipment

The laboratory at Jinxiang Second Middle School was chosen as the experimental setting, and standard lighting (a 40-watt fluorescent lamp) was used. The virtual screen's background was white, and the family's living room was the default atmosphere in virtual reality. The participant may easily alter the exact distance between themselves and the virtual screen to feel comfortable.

In terms of experimental equipment selection, the experimental program was written using Psychopy 3.0, a special development software for psychological experiments [25], and was run on a computer with a CPU main frequency of 3.0 HZ. The stimuli were presented in the center of a 17-inch monitor with a computer screen resolution of 1280 × 1024 and a brightness of 92 cd/m^2, and the material content was presented in the Oculus Quest2 with a monocular resolution of 1832 × 1920, in the Bigscreen software within the 64G device. The Oculus Quest 2's stereo speakers played the audio using a speech synthesizer, which converts the text into audio files. The participant could adjust the loudness. The specific experimental scenario is shown in Figure 5.

(**a**) (**b**)

Figure 5. Scene in virtual reality (**a**) and participant' experimental procedure (**b**).

2.6. Experimental Procedures

An indirect, impartial measurement technique was included in the experiment's design. The questions posed in this experiment were split into rote learning memory type questions and comprehension memory type questions to examine the extent of users' information cognition. This was done in order to evaluate the users' degree of processing of information during the experiment. Therefore, the experimental stage I was designed from the perspective of visual and auditory sensory to investigate the effect of different textual information presentation forms on users' cognitive load: 3 display modes (full text + audio vs. full text + key markers vs. key markers + audio) × 2 display lengths (short text vs. long text) × 2 question types (comprehension questions vs. rote learning questions) were not completely randomized. Experimental stage II was designed from the perspective of visual and auditory sensory. Phase II was a single-factor (information cues mode: visual information vs. auditory information vs. visual information + auditory information) experimental design from the perspective of visual and auditory perceptual sensory inputs for exploring the effects of different presentation forms of information cues on users' cognitive load.

Experimental stage I: The materials of the experiment were selected from 6 materials in the History of Modern World Design, with a total of 3 knowledge points; 4 questions were designed for each material, including excerpts (rote learning memorization) and word-transformation questions (comprehension). In order to avoid the bias caused by the different difficulty of the materials, the experimental materials were divided into three groups (11 subjects in each group), and the contents of the materials are shown in Figure 6.

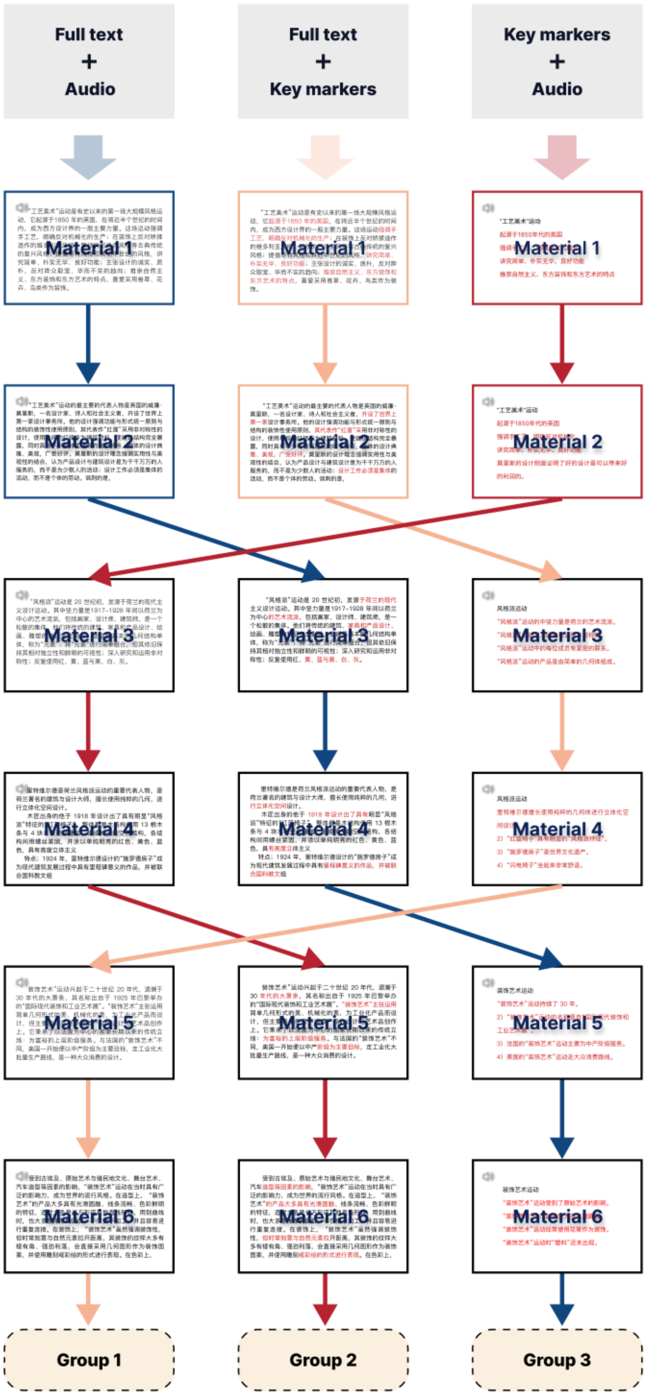


Figure 6. Experimental phase I procedure.

Experimental Phase II: The experimental material was selected from one of the materials in the History of Modern World Design, which was different from the above material, with a total of one knowledge point, and four questions related to the content of the material were designed, including questions on excerpts (rote learning memorization) and word-meaning transformation questions (comprehension), and one question related to the appearance of cue information. To control for variables, the experimental material was selected for its shorter content and presented in full text + audio, with the cues presented mainly through visual information (bolded font) and auditory information (rising volume), presented in the form shown in Figure 7.

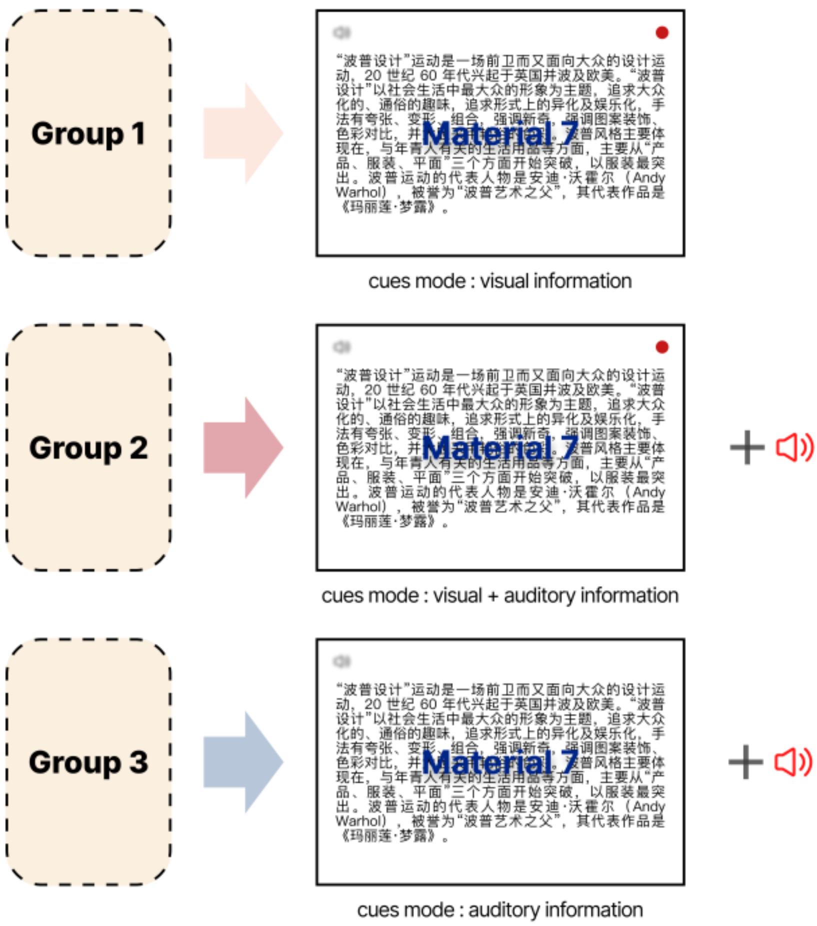


Figure 7. Experimental phase II procedure.

In terms of experimental time settings, those who spend a lot of time in the virtual environment may exhibit symptoms like exhaustion, drowsiness, and trouble focusing. According to Guo Dongyu' study [25], young people can focus for an extended period of time in a virtual environment but begin to experience visual fatigue after about 17 min. This visual fatigue is related to equipment factors, such as equipment parameters, video production parameters, and delicacy. In accordance with Guo Dongyu, using virtual reality equipment continuously should not last longer than 30 min before taking a break. The whole experimental process can be divided into four steps:

- Participants were given a thorough explanation of the experiment's goals and procedures before the experiment, and they were required to sign an informed consent form to confirm that they were aware of its details and how it would be performed;
- The participants were instructed to put on the virtual reality gear, experience the virtual reality world for five minutes, and then proceed with the experiment once they had adjusted to the virtual world and had no negative reactions;

- The reading material (n) on the display interface was given to the participant to read, listen to, and memorize. If the reading was not done in 90 s, the participant automatically switched to the question–answer mode;
- The participant was instructed to determine whether the following four questions were correct or incorrect based on their understanding of the experiment's materials (n) and to click the appropriate button (press "F" for a correct question and "J" for an incorrect question).

When the experiment starts, as shown in Figures 8 and 9, participants were first presented with a picture of a cross in the middle with a white background for 500 ms, followed by a picture of black text on a white background with textual material, and the relevant question appeared by pressing the space bar (if no action was taken, the question appears automatically after 90 s). After the subject selected the answer, feedback on the number of correct or incorrect answers and the proportion of correct answers appeared. The feedback was presented for 200 ms, and then the next question appeared automatically. After all four questions were answered, the next reading material appeared.

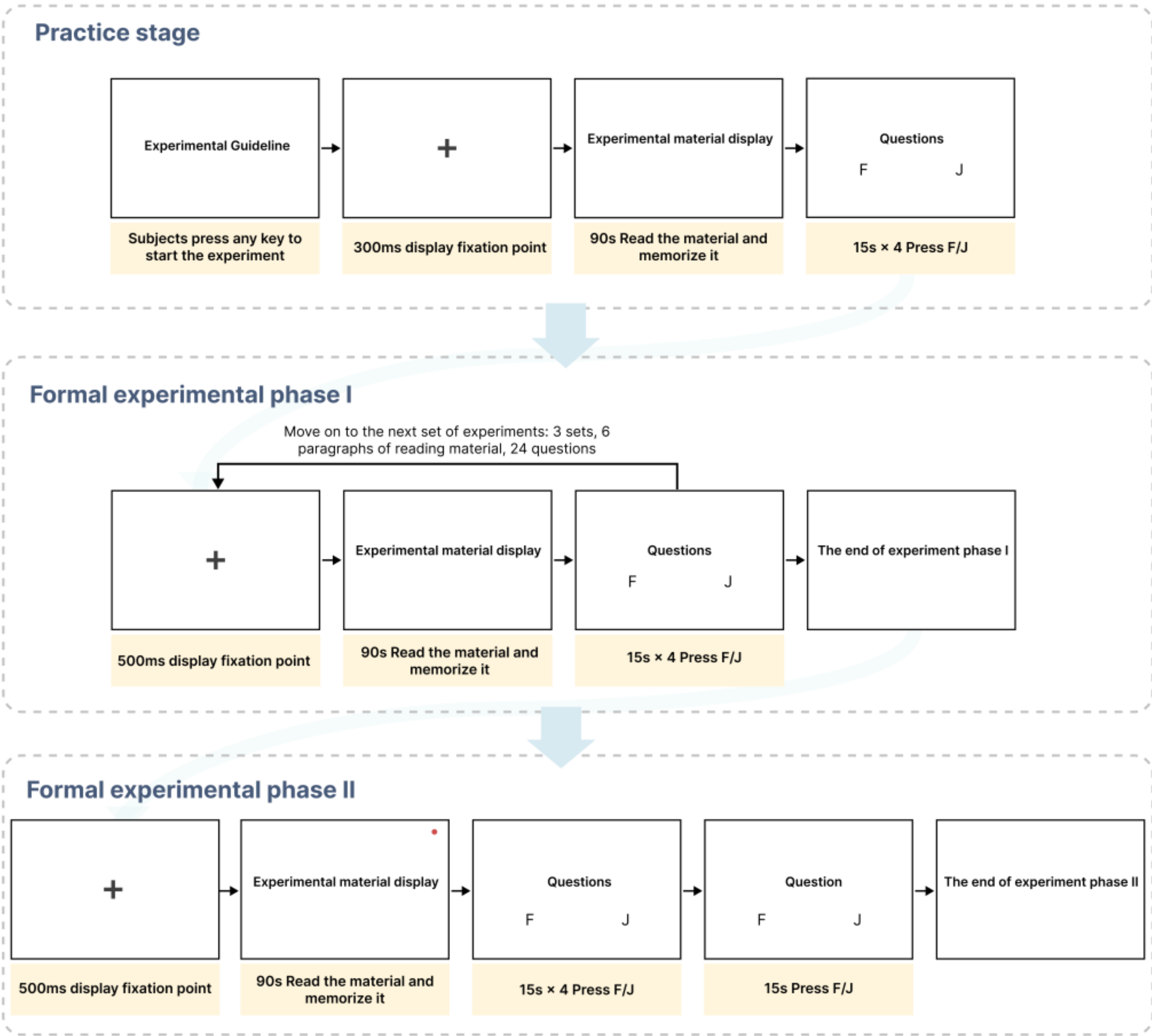


Figure 8. Experimental flow chart.

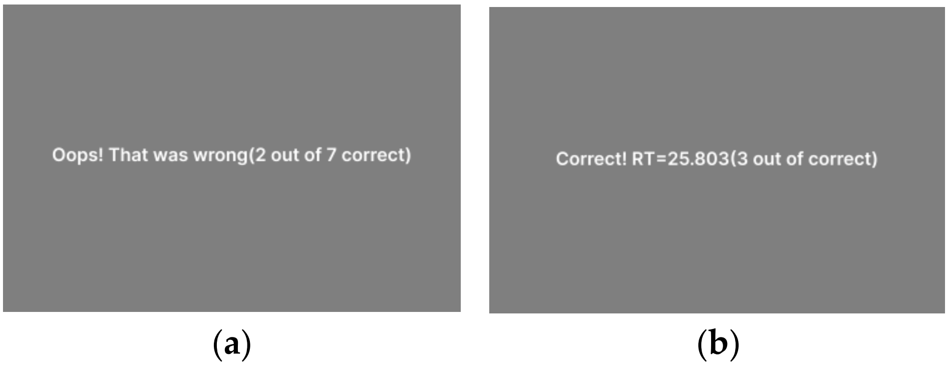


Figure 9. Answer error feedback (**a**) and correct answer feedback (**b**).

At the end of the experiment, brief interviews were conducted with the users to understand their evaluation of the different types of materials.

3. Results

An ANOVA was conducted on the response time and answer accuracy for the different presentation forms of the materials in the multi-sensory condition. The significant differences in response time and correctness rates under the effect of the three influencing factors for different types of instructional material in terms of display modes (full text + audio vs. full text + key markers vs. key markers + audio), display length (long text, short text), and question type (rote learning questions, comprehension questions) were analyzed separately.

As shown in Table 3, the main effects of response time and correctness for display mode, display length, and question type were significant (F < 0.05) at the significance level, with F = 12.581, $p = 0 < 0.05$ for display mode response time; F = 3.642, $p = 0.027 < 0.05$ for display mode correctness; F = 3.642, $p = 0.027 < 0.05$ for display length response time; F = 15.998, $p = 0.000 < 0.05$ for display length response; F = 7.148, $p = 0.008 < 0.05$ for display length correct rate; F = 7.567, $p = 0.04 < 0.05$ for question type response; and F = 9.893, $p = 0.002 < 0.05$ for question type correct rate. This indicates that different display styles, display lengths, and question types have a significant effect on response time and accuracy rate. In terms of the interaction effect between the two factors, only the display style and question type had a significant effect (F = 3.843, $p = 0.022 < 0.05$), while the others had no significant interaction effect.

The results of the DUNCAN multiple post-test comparisons of response time and correctness shown in Table 4 indicate that there was a significant difference in response time between full text + audio and the other two formats and a significant difference in correctness between full text + key markers and key markers + audio. In terms of response time, users were slower to respond to questions after having studied the full text + audio type material, while those given full text + key markers and key markers + audio performed well. In terms of correct response rate, key markers + audio had the highest correct response rate, followed by full text + audio and full text + key markers had the lowest rate. Overall, key markers + audio performed the best.

Table 3. ANOVA data main effect and interaction effect tests for response time and correctness.

Type Name		Type III Sums of Squares	df	Mean Square	F	*p*
Modified model	Reaction time	89.603 a	9	9.956	5.692	0
	Correct rate	6.659 b	9	0.74	3.639	0
Intercept distance	Reaction time	9728.043	1	9728.043	5562.207	0
	Correct rate	390.323	1	390.323	1919.49	0
Display mode	Reaction time	43.877	2	21.938	12.544	0
	Correct rate	1.487	2	0.744	3.657	0.026
Display length	Reaction time	27.897	1	27.897	15.951	0
	Correct rate	1.46	1	1.46	7.178	0.008
Question type	Reaction time	13.194	1	13.194	7.544	0.004
	Correct rate	2.02	1	2.02	9.935	0.002
Display mode & display length	Reaction time	4.575	2	2.288	1.308	0.271
	Correct rate	0.003	2	0.001	0.006	0.994
Display mode & question type	Reaction time	0.02	2	0.01	0.006	0.994
	Correct rate	1.563	2	0.782	3.843	0.022
Display length & question type	Reaction time	0.04	1	0.04	0.023	0.88
	Correct rate	0.126	1	0.126	0.621	0.431
Error	Reaction time	1367.682	782	1.749		
	Correct rate	159.018	782	0..203		
Total	Reaction time	11,185.328	792			
	Correct rate	556	792			
Total after correction		1457.285	791			
		165.677	791			

a. R^2 = 0.061 (Adjusted R^2 = 0.051); b. R^2 = 0.040 (Adjusted R^2 = 0.029).

Table 4. DUNCAN post hoc multiple comparison results showing mode response time and correctness.

Type	*N*	Reaction Time	Correct Rate
Full text + audio	264	3.82 ± 1.47	0.69 ± 0.47
Full text + key marker	264	3.25 ± 1.23	0.66 ± 0.47
Key marker + audio	264	3.45 ± 1.31	0.76 ± 0.43
F		12.247	3.574
p		0.000	0.029

The descriptive statistics of response time and correctness shown in Table 5 indicate that longer texts were learned with faster responses to questions and higher correct response rates. Taking into account the schema construction theory, for independent brief information, although it is easy to make short-term memories with low cognitive load intensity, at the same time, if the learning time is short, it is difficult for users to quickly establish connections between the associable information and the original cognitive information to form long-term memories; instead, more cognitive load is generated, so the overall learning effectiveness is rather inferior to that of longer learning materials.

Table 5. Descriptive statistics showing length of response time and correct rate.

Type	*N*	Reaction Time	Correct Rate
Short text	264	3.69 ± 1.37	0.66 ± 0.48
Long text	264	3.32 ± 1.32	0.74 ± 0.44
F		15.418	7.022
p		0	0.008

The descriptive statistics of response time and correctness shown in Table 6 show that users were faster when facing comprehension questions, but their correctness rate was lower than rote learning questions. For the overall learning process, users performed better when answering rote learning questions.

Table 6. Results of descriptive statistics of response time and correctness for question types.

Type	*N*	Reaction Time	Correct Rate
Rote learning questions	396	3.63 ± 1.35	0.75 ± 0.43
Understanding questions	396	3.38 ± 1.35	0.65 ± 0.48
F		7.218	9.752
p		0.007	0.002

As can be seen in the correctness data shown in Table 7, users performed well with higher correctness rates for rote learning questions and poorly for comprehension questions in the key markers + audio vs. full text + key markers material, while the opposite was true in the full text + audio material.

Table 7. Descriptive statistics for display mode and question type.

Type	Question Type	*N*	Correct Rate
Full text + Audio	Rote learning questions	132	0.67 ± 0.04
	Understanding questions	132	0.7 ± 0.04
Full text + Key markers	Rote learning questions	132	0.75 ± 0.04
	Understanding questions	132	0.57 ± 0.04
Key markers + Audio	Rote learning questions	132	0.83 ± 0.04
	Understanding questions	132	0.69 ± 0.04
F			3.843
p			0.022

An ANOVA was conducted on the presence or absence of information cues on response time and correctness in the multi-sensory condition and, as shown in Table 8, there was no significant difference between user response time ($F = 0.562$, $p = 0.454 > 0.05$) and correctness ($F = 1.744$, $p = 0.188 > 0.05$) with or without the effect of cueing materials. This indicates that the presence or absence of cueing materials did not have a significant interfering effect on user perceptions.

Table 8. Results of descriptive statistics of response time and correctness in conditions with and without information cues.

Type	*N*	Reaction Time	Correct Rate
With information cues	132	3.22 ± 1.46	0.8 ± 0.4
Without information cues	132	3.07 ± 1.82	0.86 ± 0.34
F		0.562	1.744
p		0.454	0.188

The relationship between different message prompting modes on the correct rate of information cues under multi-sensory conditions was further investigated and, as shown in Table 9, there was a significant difference in the correct rate of user responses ($F = 7.309$, $p = 0.000 < 0.05$) under the effect of prompting modes for different sensory inputs.

Table 9. Results of the DUNCAN post-test multiple comparisons of response time and correctness of multi-sensory message prompting methods.

Type	*N*	Correct Rate
Vision	11	0.27 ± 0.45
Vision + Auditory	11	0.64 ± 1.49
Auditory	11	0.73 ± 0.45
F		7.309
p		0.000

4. Discussion

The users learned most effectively with key marker + audio material, which had the highest correct rate and was appropriate for general teaching scenarios. Full text + audio material had a slower response time when answering questions and used up more mental cognitive resources when reading. Full text + key markers had the lowest correct rate, had poor learning performance, and was not appropriate for learning activities with more content.

Those who learned longer texts responded to questions more quickly and answered correctly more frequently. It is clear that under certain cognitive loads, learning outcomes can be improved.

The users performed better on the rote learning memorization problems, even though they could answer comprehension questions more quickly, but the correct response rate was somewhat lower.

The users studying full text + audio content exhibited better comprehension of the topic and performed better when answering comprehension questions than users studying the other two varieties; however, they took longer to respond to the questions.

When we compare the percentage of correct responses to questions with materials that contain various information cueing techniques, we can see that auditory information had more of an impact on users and that users were better able to recognize the content of information cues than purely visual information.

5. Conclusions

In terms of the presentation of material content, depending on the application scenario and material content, designers can choose the appropriate presentation format to match the user's cognitive ability and learning needs.

(1) For the single sensory modality, visual learning presentation (full text + key markers), although the readability of information was improved by means of key markers, and its presentation format is most familiar to high school students, who can read and reflect faster, the load on the visual sense is too heavy for long-term learning, and the cognitive load of users was too strong. They were more likely to have problems answering questions at a later stage or even to know the answer but choose the wrong one. In view of its fast reading speed, this type of presentation can be applied to overview learning, such as the description of collections in history museums, so that students can quickly understand the information but do not need to rigidly memorize it.

(2) For the overlapping learning presentation of audio and visual information (full text + audio), although multiple sensory channels receive the same information simultaneously to complement each other, it also tended to cause redundancy of information and consume more cognitive resources. In addition, the reception speed of auditory information was much slower than that of visual information, which leads to the unsynchronized reception of both types of information and consumes more mental cognitive resources to offset the information bias between visual and auditory cognition, so participants given this type of information presentation performed relatively poorly. However, for difficult learning materials, this mode can provide clearer and more comprehensive cognitive learning. Therefore, by controlling the presentation speed of visual information and balancing the information presentation bias between the two, it can perform better in practical applications.

(3) For the semi-overlapping learning presentation form of visual and auditory information (key markers + audio), the visual sense was used to sense the auditory focus information, which can quickly understand the general content of auditory information and can allocate mental cognitive resources more rationally for cognitive learning of the content of auditory information. However, the presentation of auditory information had difficult inducing a high accuracy, and the user's speed of understanding the information needs to match the speed of presentation of auditory information, which has higher requirements. In practical applications, the combination with immersive image information can assist in building illustrations and produce better learning outcomes.

In terms of content length, the completeness and logic of the course at this teaching stage should be under the premise that the fixed teaching time is within 30 min. According to the richness of the teaching content, the material with a wide variety of content should be divided into broad categories, or a small amount of independent information should be integrated on the page to prevent fragmented information from increasing the complexity of the learning operation.

In terms of test questions, the questions should be set from easy to difficult, starting with rote learning memory and gradually going deeper into comprehension memory content, which can easily increase the level of cognitive arousal of users and deepen their understanding of the material content. In addition, it is better to set the questions in line with the user's cognitive ability and to conduct a memory-deepening test directly after learning the same type of teaching content, which can be mainly rote learning memory type questions with corresponding correct and incorrect feedback that can deepen the user's impression of the previous learning. After the whole chapter is finished, a deeper question test can be conducted that can focus on comprehension memory points and provide corresponding feedback to further improve the user's understanding of the content.

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Appendix A

Appendix A.1. Materials

Appendix A.1.1. Material 1

Original text: “ 工艺美术” 运动是有史以来的第一场大规模风格运动，它起源于 1850 年的英国，在将近半个世纪的时间内，成为西方设计界的一股主要力量。这场运动强调手工艺，明确反对机械化的生产；在装饰上反对矫揉造作的维多利亚风格、繁琐的巴洛克风格等古典传统的复兴风格；提倡哥特风格和其他中世纪的风格，讲究简单、朴实无华、良好功能；主张设计的诚实、质朴，反对哗众取宠、华而不实的趋向；推崇自然主义、东方装饰和东方艺术的特点，喜爱采用卷草、花卉、鸟类作为装饰。

实验材料1 问题:

1. “ 工艺美术” 运动持续了一个世纪。
2. “ 工艺美术” 运动中的设计推崇自然。
3. “ 工艺美术” 运动强调机械化的生产，明确反对手工艺。
4. “ 工艺美术” 运动提倡哥特风格和其他中世纪的风格。

Translated text: The Arts and Crafts movement was the first major style movement in history. It originated in England in 1850 and became a guidepost for the development of Western design for nearly half a century. The movement emphasized craftsmanship and explicitly opposed mechanized production; it opposed the classical traditional revival styles such as the pretentious Victorian style and the cumbersome Baroque style in decoration; it advocated the Gothic style and other medieval styles, which were simple, unpretentious, and functional; it advocated honesty and simplicity in design and opposed the tendency to be flashy and unrealistic; and it promoted naturalism and oriental decoration and loved to use curly grass, flowers, and birds as decoration.

Experimental Materials 1 Questions:

1. The "Arts and Crafts" movement lasted for a century.
2. The design of the "Arts and Crafts" movement respected nature.
3. The "Arts and Crafts" movement emphasized mechanized production and explicitly opposed handicrafts.
4. The "Arts and Crafts" movement promoted the Gothic style and other medieval styles.

Appendix A.1.2. Material 2

Original text: " 工艺美术" 运动的最主要的代表人物是英国的威廉· 莫里斯，一名设计家、诗人和社会主义者，开设了世界上第一家设计事务所。他的设计强调功能与形式统一原则与结构的装饰性使用原则，其代表作" 红屋" 采用非对称性的设计，使用单纯的红砖作为建筑材料，使建筑结构完全暴露，同时具有不少哥特式建筑的细节特点，整体的设计典雅、美观，广受好评。

莫里斯的设计理念强调实用性与美观性的结合，认为产品设计与建筑设计是为千千万万的人服务的，而不是为少数人的活动；设计工作必须是集体的活动，而不是个体的劳动。讽刺的是，他的设计由于成本太高，只有富裕家庭才能买得起。他所追求的大众品味的提高，却是由那些抄袭了他的设计，再用较低成本的机械批量化生产出来再出售给各个阶层的制造商完成的，这也侧面证明了：好的设计是可以带来好的利润的。他让许多制造商产生了对于好的设计师的渴求。

实验材料2 问题:

5. 莫里斯认为设计是为少数人服务的
6. " 红屋" 将红砖作为建筑材料，并采用非对称性的设计。
7. 莫里斯是法国的设计家。
8. 莫里斯的设计侧面证明了好的设计是可以带来好的利润的。

Translated text: The foremost proponent of the Arts and Crafts movement was William Morris, a British designer, poet, and socialist who founded the world′s first design office. His designs emphasize the principles of unity of function and form and the decorative use of structures. His masterpiece, The Red House, is an asymmetrical design, using simple red brick as the building material, leaving the structure completely exposed, while reflecting many of the details of Gothic architecture.

Morris′s design philosophy emphasizes the combination of practicality and aesthetics, believing that product design and architectural design are for millions of people and that design must be a collective activity. Ironically, his designs were so costly that only the wealthy could afford them. The improvement in public taste that he sought was achieved by manufacturers who copied his designs and mass-produced them with lower-cost machinery for sale to all classes, proving that good design can produce good profits. This is proof of the fact that good design can produce good profits. It has led many manufacturers to seek out good designers.

Experimental Materials 2 Questions:

5. Morris believed that design was for the few.
6. The Red House uses red bricks as building materials and has an asymmetrical design.
7. Morris was a French designer.
8. Morris's design is proof that good design can lead to good profits.

Appendix A.1.3. Material 3

Original text: " 风格派" 运动是 20 世纪初，发源于荷兰的现代主义设计运动。其中坚力量是 1917–1928 年间以荷兰为中心的艺术流派，包括画家、设计师、建筑师，是一个松散的集体。他们将传统的建筑、家具和产品设计、绘画、雕塑的特征完全剥除，变成最基本的几何结构单体，称为" 元素"；将" 元素" 进行简单组合，但其依旧保持其相对独立性和鲜明的可视性；深入研究和运用非对称性；反复使用红、黄、蓝与黑、白、灰。

实验材料3 问题:

9. " 风格派" 运动的中坚力量是荷兰的艺术流派。
10. " 风格派" 运动深入研究和运用非对称性。
11. " 风格派" 运动中的每位成员有紧密的联系。

12. “ 风格派” 运动的产品是由简单的几何体组成。

Translated text: The Stylistic movement was a modernist design movement that originated in the Netherlands at the beginning of the 20th century. Its mainstay was the Dutch-centered art school of painters, designers, and architects, a heterogeneous collective from 1917 to 1928. They stripped away the traditional features of architecture, furniture and product design, painting, and sculpture into the most basic geometric monoliths called ‘elements’. Simple combinations of ‘elements’ still retained their relative independence and distinct visibility; in-depth study and use of asymmetry; and repeated use of red, yellow, and blue with black, white and, grey.

Experimental Material 3 Questions:

9. The mainstay of the Stylistic movement was the Dutch school of art.
10. The Stylistic movement delved into the study and use of asymmetry.
11. Each member of the Stylistic movement was closely related.
12. The products of the Stylistic movement were made up of simple geometric forms.

Appendix A.1.4. Material 4

Original text: 里特维尔德是荷兰风格派运动的重要代表人物，是荷兰著名的建筑与设计大师，擅长使用纯粹的几何，进行立体化空间设计。

木匠出身的他于 1918 年设计出了具有明显“ 风格派” 特征的“ 红蓝椅子” ，整体都是木结构使用13 根木条与4 块木板交叉叠加，组成椅子的空间结构，各结构间用螺丝紧固，并涂以单纯明亮的红色、黄色、蓝色，具有高度立体主义特点；

1924 年，里特维尔德设计的“ 施罗德房子” 成为现代建筑发展过程中具有里程碑意义的作品，并被联合国科教文组织定为世界文化遗产；

1934 年，里特维尔德的设计美学已经非常娴熟了，其设计的闪电椅子拥有折纸般的曲线，整体呈现“Z” 型，即使不使用鲜亮的色彩，仅凭纯粹的几何形式就能达到设计的目的。他打破了人们对椅子的固有看法，设计了这张看起来不舒服坐起来也不舒服的椅子。“ 你想坐的舒服点，那就躺在床上。”

实验材料4 问题:

13. 里特维尔德擅长使用纯粹的几何体进行立体化空间设计。
14. “ 红蓝椅子” 具有明显的“ 风格派特征” 。
15. “ 施罗德房子” 是世界文化遗产。
16. “ 闪电椅子” 坐起来非常舒适。

Translated text: Rietveld was an important figure in the Dutch stylistic movement and was a renowned Dutch architect and designer, specializing in the use of pure geometry and three-dimensional space design.

In 1918, he designed the Red and Blue Chair, a distinctly Stylistic design, with a wooden structure using 13 strips of wood and four planks stacked on top of each other to form the spatial structure of the chair, which is screwed together and painted in bright red, yellow, and blue, with a highly cubist character.

In 1924, Rietveld’s Schroeder House became a landmark in the development of modern architecture and was designated a World Heritage Site by UNESCO.

By 1934, Rietveld’s design aesthetic had become so sophisticated that his Lightning Chair, with its origami-like curves and ‘Z’ shape, was designed to be purely geometric, even without the use of bright colors. He broke the mold of what a chair should look like and designed it to look uncomfortable and sit uncomfortably. “You want to sit comfortably, then lie on the bed”.

Experimental Materials 4 Questions:

13. Rietveld specialized in the use of pure geometry for three-dimensional spatial design.
14. The Red and Blue Chair has a clear Stylistic character.
15. The Schroeder House is a World Heritage Site.
16. The Lightning Chair is very comfortable to sit in.

Appendix A.1.5. Material 5

Original text: "装饰艺术" 运动兴起于二十世纪 20 年代，退潮于 30 年代的大萧条，其名称出自于 1925 年巴黎举办的"国际现代装饰和工业艺术展"。"装饰艺术" 主张运用简单几何形式的美、机械化的美，为工业化产品而设计，但主要集中在奢华消费产品的设计与艺术品创作上。它秉承了以法国为中心的国家长期以来的传统立场：为富裕的上层阶级服务。与法国的"装饰艺术" 不同，美国一开始便以中产阶级为主要目标，走工业化大批量生产路线，是一种大众消费的设计。

实验材料5 问题:

17. "装饰艺术" 运动持续了30 年。
18. "装饰艺术" 运动的名称源自"国际现代装饰和工业艺术展"。
19. 法国的"装饰艺术" 运动主要为中产阶级服务。
20. 美国的"装饰艺术" 运动走大众消费路线。

Translated text: The Art Deco movement, which emerged in the 1920s and ebbed in the 1930s during the Great Depression, began in 1925 with the International Exhibition of Modern Decorative and Industrial Art in Paris. Art Deco advocated the use of simple geometric forms, mechanized beauty, and design for industrial products, but focused mainly on the design of luxury consumer products and the creation of artworks. It follows a long-standing tradition in the countries centered around France: to serve the wealthy upper classes. In contrast to French Art Deco, the United States began with the middle class as the main target, with industrial mass production, a design for mass consumption.

Experimental Material 5 Questions:

17. The Art Deco movement lasted 30 years.
18. The Art Deco movement began with the International Exhibition of Modern Decorative and Industrial Arts.
19. The Art Deco movement in France was mainly for the middle classes.
20. In the United States, the Art Deco movement was for the general public.

Appendix A.1.6. Material 6

Original text: 受到古埃及、原始艺术与殖民地文化、舞台艺术、汽车造型等因素的影响，"装饰艺术" 运动在当时具有广泛的影响力，成为世界的流行风格。

在造型上,"装饰艺术" 的产品大多具有光滑圆融、线条流畅、色彩鲜明的特征，造型大多是长方形或其他直线形状，用到曲线时，也大多是浑厚的圆弧，不仅便于加工，并且容易进行重复连接。

在装饰上，"装饰艺术" 虽然强调装饰性，但时常刻意与自然元素拉开距离，其装饰的纹样大多有棱有角、强劲利落，会直接采用几何图形作为装饰图案，并使用雕刻或彩绘的形式进行表现。

在色彩上，"装饰艺术" 具有强烈鲜明的色彩特征，重视红、黄、蓝和金属色彩，同时喜爱黑色和烟灰色，色彩对比强烈大胆；

在材料上，"装饰艺术" 热爱采用名贵的材料与闪亮的金属来打造现代、华丽的氛围。不仅如此，在当时属于创新材料的塑料也被广泛应用于家具与首饰设计中。

实验材料6 问题:

21. "装饰艺术" 运动受到了原始艺术的影响。
22. "装饰艺术" 的产品造型大多光滑圆融。
23. "装饰艺术" 运动经常使用花草作为装饰。
24. "装饰艺术" 运动时"塑料" 还未出现。

Translated text: Influenced by ancient Egyptian, primitive and colonial art, theater art, and, car modelling, the Art Deco movement was widely influential and became a popular style worldwide.

In terms of shape, Art Deco products were mostly characterized by smooth, rounded, smooth lines and vibrant colors, with most shapes being rectangular or otherwise straight; when curves were used, they were mostly thick, rounded arcs that were easy to work with and easy to join repeatedly.

In terms of decoration, although Art Deco emphasizes ornamentation, it remains distinct from the natural elements, with the majority of its decorative motifs being rigid in style, using geometric shapes directly as decorative motifs, and using carved or painted forms of expression.

In terms of color, Art Deco has a strong color identity, with a strong emphasis on red, yellow, blue, and metallic colors, as well as a preference for black and anthracite, with strong color contrasts.

In terms of materials, Art Deco is a modern, ornate style, using precious materials and shiny metals. In addition, plastic, an innovative material at the time, was also used in furniture and jewelry design.

Experimental Materials 6 Questions:

21. The Art Deco movement was influenced by primitive art.
22. The Art Deco products were mostly smooth and rounded in shape.
23. The Art Deco movement often used flowers and plants as decoration.
24. Plastic did not exist at the time of the Art Deco movement.

Appendix A.1.7. Material 7

Original text: “波普设计”运动是一场前卫而又面向大众的设计运动，20 世纪 60 年代兴起于英国并波及欧美。“波普设计”以社会生活中最大众的形象为主题，追求大众化的、通俗的趣味，追求形式上的异化及娱乐化，手法有夸张、变形、组合，强调新奇，强调图案装饰、色彩对比，并大胆采用艳俗的色彩。波普风格主要体现在，与年青人有关的生活用品等方面，主要从“产品、服装、平面”三个方面开始突破，以服装最突出。波普运动的代表人物是安迪·沃霍尔（Andy Warhol），被誉为“波普艺术之父”，其代表作品是《玛丽莲·梦露》。

实验材料7 问题:

25. “波普设计”产品主要采用较为清淡的色彩。
26. “波普设计”的代表作品之一是《玛丽莲·梦露》。
27. “波普设计”运动于 1960 年兴起于英国。
28. “波普设计”运动体现在中老年的生活用品中。

Translated text: Pop Design is an avant-garde and popular design movement that emerged in Britain in the 1960s and spread to Europe and America. Pop Design is based on the most popular images in social life, pursuing the interest of the masses, the pursuit of formal alienation and entertainment, the emphasis on graphic decoration, color contrast, and the bold use of gaudy colors. The Pop style was mainly reflected in the lifestyle products related to young people, mainly in the three areas of products, clothing, and graphics. The Pop movement is represented by Andy Warhol, known as the father of Pop Art, whose representative work is Marilyn Monroe.

Experimental Material 7 Question:

25. Pop Design products are mainly in lighter colors.
26. One of the most iconic works of Pop Design is Marilyn Monroe.
27. The Pop Design movement emerged in Britain in 1960.
28. The Pop Design movement is reflected in the lifestyle products of middle-aged and elderly people.

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