



**International Journal of Continuing Engineering Education
and Life-Long Learning**

ISSN online: 1741-5055 - ISSN print: 1560-4624

<https://www.inderscience.com/ijceell>

**Learners' eye movement behaviour in a conceptual knowledge
video lecture: a Chinese case study**

Xiaojin Wang, Jinyou Zou, Dongmei Tang

DOI: [10.1504/IJCEELL.2025.10071949](https://doi.org/10.1504/IJCEELL.2025.10071949)

Article History:

Received: 25 September 2024

Last revised: 04 May 2025

Accepted: 08 May 2025

Published online: 19 September 2025

Learners' eye movement behaviour in a conceptual knowledge video lecture: a Chinese case study

Xiaojin Wang* and Jinyou Zou

School of Educational Sciences,
Guangdong Polytechnic Normal University,
No. 293, West Zhongshan Dadao,
Tianhe District, Guangzhou,
510665, China
Email: wangxiaojin@m.scnu.edu.cn
Email: zoujinyou2028@163.com
*Corresponding author

Dongmei Tang

Guizhou University,
Huaxi District, Guiyang City,
Guizhou Province, 550025, China
Email: tangdm@m.scnu.edu.cn

Abstract: In MOOCs, video lectures are widely used, yet how to design them effectively based on knowledge type remains underexplored. This study investigates learners' eye movement behaviours and conceptual knowledge acquisition while watching a six-minute video lecture. Twenty-six university students participated by viewing the video and completing a conceptual knowledge test. Eye-tracking technology was used to collect data on pupil position, fixation time, and gaze paths, generating indices such as heat maps and viewing durations for areas of interest. Results indicate: 1) learners' attention was evenly distributed across the four concept elements – name, definition, attribute, and example; 2) highlighted content (e.g., in red) drew more attention; 3) no significant differences were found in eye movement behaviours between high- and low-performing students; 4) no gender-based differences were observed in fixation times. These findings provide empirical insights into video lecture design, suggesting that emphasising key content visually may enhance learners' attention without necessarily affecting performance outcomes.

Keywords: video lecture; conceptual knowledge learning; eye movement behaviour; cognitive processing; influencing factor.

Reference to this paper should be made as follows: Wang, X., Zou, J. and Tang, D. (2025) 'Learners' eye movement behaviour in a conceptual knowledge video lecture: a Chinese case study', *Int. J. Continuing Engineering Education and Life-Long Learning*, Vol. 35, No. 5, pp.435–448.

Biographical notes: Xiaojin Wang has a PhD in Educational Technology and is an Associate Professor and Master's Supervisor. Her research focuses on educational digitalisation, applications of artificial intelligence in education, and vocational and technical education.

Jinyou Zou is a Master's student in Modern Educational Technology at Guangdong Polytechnic Normal University. Her research interests include digital learning, maker education, and technology-supported teaching practices. She has participated in projects related to digital literacy development in secondary education and is particularly focused on how project-based learning can enhance students' technological competencies.

Dongmei Tang is an Assistant Laboratory Technician at the Modern Educational Technology Center of Guizhou University. She holds a Master of Science in Educational Technology and research focuses on modern educational technology.

1 Introduction

With the popularisation and development of online networks, online learning has become an important learning mode, and video resources have become important materials for presenting information. Thus, considerable attention has been paid to the availability of video resources. Traditional methods for evaluating video resource availability include indicator statistics, questionnaire surveys and task analysis. With the continuous improvement of the manufacturing accuracy of eye trackers, the use of eye movement behaviour analysis technology to examine the usability of videos has increased. Eye trackers can compensate for the shortcomings of traditional methods, which cannot directly investigate users' internal cognitive processing. Research on eye movement technology developed rapidly at home and abroad in recent years. Current research on eye movement focuses mainly on visual information processing and rapid reading, eye movement and language processing in reading, computational models for eye movement control in reading, eye movement in human–computer interactions and eye movement in media application and communication. In visual information presentation, a close relationship exists between eye gaze and attention. Visual attention is an important component of the human visual system, which is closely related to eye movement and information processing.

This research focuses on a conceptual knowledge video lecture. In psychology, ‘concept’ refers to a class of objects or properties represented by symbols or a collection of essential attributes that distinguish a class of objects from another class of objects. A concept generally consists of four components: the concept name, concept definition, concept example and concept attribute. The concept name is a symbol that integrates sound and action, the concept definition is a phrase stating the essential characteristics of the concept, the concept example represents a specific object and the concept attribute represents a characteristic of an object that distinguishes it from other objects. Concepts, principles and theories in various disciplines are classified as conceptual knowledge.

In this study, the experiment method is used to examine the characteristics of college students' eye movement behaviour when watching online video resources to provide suggestions for video resource design. This study mainly examines the distribution of learner's attention whilst watching a conceptual learning video, the impact of the key parts of the video (information marked in red, highlighted and so on) on the learners, the correlation between test scores and the eye movement indicators and whether differences exist in the mean gaze time of the participants depending on their gender.

2 Literature review

A concept is the basis of a knowledge structure and a node in a networked cognitive structure (Chen and Zhang, 2019). According to the theory of meaningful acceptance learning developed by Ausubel, concept learning can be divided into two processes, namely, concept formation and concept assimilation, which are learning methods used to grasp a concept or a phenomenon (Su, 2022). Conceptual knowledge can be divided into three types: knowledge of categories and classifications, knowledge of principles and generalisations and knowledge of theories, patterns and structures (Wang et al., 2020). Information processing psychologist John Robert Anderson used computer information processing to simulate the knowledge processing of the human brain and divided knowledge into two categories, namely, declarative knowledge and procedural knowledge (Xie et al., 2021). The above pedagogical knowledge reveals that declarative knowledge is the basis of conceptual knowledge. Moreover, relevant studies showed that learner's mastery of procedural knowledge requires the support of teaching video resources (Lu and Yang, 2016). In the current social era of transition from digitalisation to digitalisation, online learning has become the norm, and the learning and mastery of declarative knowledge cannot be achieved without video teaching materials, which have become the preferred resources for digital learning.

Some researchers conducted research from the perspective of horizontal comparison and vertical development and proposed that declarative knowledge learning should be closely related to the learning environment and learning resources to strengthen students' understanding, and theoretical knowledge and practice should be combined to promote the improvement of the learning effect. Horizontal comparison involves the two perspectives of different disciplines and different teaching methods. In terms of different disciplines, Huang (2022) pointed out that the creation of diversified situations is necessary for teaching the conceptual knowledge of electromagnetism in physics to enable students to transform abstract concepts into concrete knowledge. Yang (2023) believed that the key to teaching geography lies in students' access to diversified learning support, including not only paper learning materials but also online learning resources, such as animation and videos, and indicated that personalised learning resources can promote students' deep learning. With regard to different teaching methods, Jia et al. (2024) used virtual reality and other technologies to simulate the experiment process and demonstrate the application of content in actual operations to help learners clearly understand its connotation and extension. Meanwhile, Ozcelik et al. (2010) found that changing the colour of content labels in videos can improve learner's memory and deepen their understanding of the teaching content and enhance the video learning effect.

However, views on whether instructional videos add visual cues to key parts to help students' memory and improve their academic performance are conflicting, such as the principle of redundancy among the multimedia teaching principles developed by Mayer and theory of social existence (Wang et al., 2018). The principle of redundancy holds that visual cues, such as colours and arrows, do not represent the meaning of teaching content in the teaching process, and dynamic changing information will considerably draw learner's attention (Mayer, 2005). For example, Pi et al. (2017) found that adding arrow cues to teaching videos will not increase learner's attention to the corresponding content and recognition and transfer performance. Therefore, the results of Pi et al. are in line with the redundancy principle among multimedia teaching principles. However, previous

studies showed that the setting of cues in digital learning resources has a function of not only attention guidance but also knowledge organisation and integration for learners (Mayer and Chandler, 2001; Liu et al., 2021) argued that creating a highly immersive learning environment with the help of VR devices, combining theory of ‘learning by doing’ and completing tasks interactively in a VR environment will help learners deeply process, transfer and apply knowledge and promote deep-oriented learning inputs. The research results supported the view of social existence theory, which states that the presentation of clues in video teaching can stimulate students’ learning interest and motivation, enhance their social and cultural experiences, reduce their loneliness in online learning and increase their learning engagement and concentration (Wang et al., 2018).

In recent years, the rapid development of digital technologies represented by cloud computing, artificial intelligence, blockchain technology, metacomes and so on has prompted learning methods research to focus on behavioural aspects and many researchers to adopt eye-tracking technology to examine learner’s eye movement behaviour under different conditions to reveal the cognitive mechanisms of human learning (Wang et al., 2019b). According to the eye–brain hypothesis, a learner’s fixation on a certain information and psychological information processing are simultaneous, that is, the total fixation time for a certain information is the processing time for the information. Thus, some researchers used eye-tracking technology to explore the influence of teachers’ behaviour on learners. For example, with the help of eye-tracking technology and a questionnaire survey, Wang et al. (2018) showed that teachers’ eye movement can not only guide learners to allocate visual attention to the corresponding learning content but also enhance Learner’s sense of social presence and the learning effect. In addition, teachers’ pointing gestures have been proven to improve students’ academic performance more than nonhuman cues and non cues (Pi et al., 2017). Previous eye movement studies revealed that individual eye movement-related indicators can be used to reflect learner’s cognitive processing. For example, fixation duration is the time that human eyes stay focused on a fixation point, which can reflect a learner’s cognitive effort. Meanwhile, the visit count refers to the relative static state between two saccades in the process of reading or visual searching, which can be used to reflect the cognitive load of a learner. Thus, eye-tracking technology can be employed in multimedia learning research to reveal learner’s cognitive processing.

In summary, course videos have become important resources for online teaching, and the presentation and effectiveness of video resources have received increasing attention. However, previous studies focused mainly on the effects of cueing and teachers’ behaviour on learner’s attention allocation, learning experience and learning performance in video teaching. Declarative knowledge teaching videos as learning materials to explore learner’s behaviour are relatively few. Therefore, based on meaningful learning theory and cognitive processing theory, this study adopts eye movement technology and a conceptual knowledge teaching video as a learning material to explore the distribution of learner’s attention in a conceptual learning video, the impact of the key parts of the video (information marked in red, highlighted and so on) on the learners, the correlation between test scores and the eye movement indicators and whether differences exist in the average fixation time between learners of different genders to provide a valuable reference for the optimisation of the teaching design of online video courses and improvement of the learning effect.

3 Research methods

3.1 Experiment objectives

This study aims to investigate the effects of visual attention cues in instructional videos and their relationship with learners' cognitive processing and performance. The specific objectives are as follows:

- 1 To examine the impact of visual attention cues (e.g., annotations) in video materials on learners' visual attention distribution.
- 2 To analyse the relationship between learners' eye movement behaviours and their test performance outcomes.
- 3 To identify and compare the visual attention patterns demonstrated by learners when engaging with different types of video modules.

3.2 Experiment equipment

The eye tracker used for the experiment was a Tobii Pro X3-120, with a sampling rate of 120 Hz, and the supporting software was Tobii Studio. One of the advantages of the eye tracker is that it frees the participant from wearing any type of equipment, because the eye tracker can be mounted on a laptop computer. The participant's head could move freely within a small range; thus, they were able to participate in the experiment in a comfortable and free state, and the experiment data obtained were close to reality. The participants watched a six-minute-long learning video on a 24-inch display with a resolution of 1,024 pixels by 768 pixels and listened to the video audio through headphones connected to a computer.

3.3 Participants

The experiment participants were 26 college sophomores from China between the ages of 18 and 25 years. Among the participants, 16 were female, and 10 were male. Moreover, all the participants had experience in using online videos for learning, that is, the participants were proficient in video learning.

3.4 Experiment material

The material used for the experiment was a self-made video titled 'What is knowledge?' The video integrated the concept learning components of declarative knowledge, namely, the concept name, definition, example and attribute. Camtasia 9 screen recording software was used for the video recording, and the length of the video learning resource was around six minutes, as shown in Figure 1.

3.5 Experiment process

Before the start of the experiment, the participants were asked to answer a basic information questionnaire to ensure that they met the vision requirements. The

experiment was divided into two stages to ensure the reliability of the experiment results: the pre-experiment stage and the formal experiment stage.

- 1 Pre-experiment stage: A total of five participants were randomly selected for the pre-experiment. The aim of the pre-experiment was to familiarise the participants with the experiment process and to enable the researchers to address any problems observed in the experiment.
- 2 Formal experiment stage: The experiment was conducted at the Institute of Modern Distance Education of H University, which helped ensure that the learners were in a natural state and reduced the influence of irrelevant factors on the experiment results. The duration of the whole process was around 15 minutes per participant.

Figure 1 Screenshot of video material (see online version for colours)



The procedure for a formal experiment consists of the following seven steps.

- 1 All the participants were randomly numbered.
- 2 The participants were instructed to enter the laboratory and familiarise themselves with the experiment environment. The experiment guidance was presented to the participants.
- 3 The participants were instructed to adjust their seat back and sitting posture and complete the fixation point experiment before answering the test questions.
- 4 The participants were instructed to learn the video material until the experiment material was presented.
- 5 The participants were instructed to scan the code to complete the learning test.
- 6 The participants were instructed to answer the questionnaire and participate in an interview.
- 7 All the steps, starting with step 2, were repeated for all the participants.

3.6 Basis for eye movement metric selection

To effectively evaluate learners' cognitive processing while watching instructional videos, this study adopted specific eye movement indicators grounded in cognitive psychology and multimedia learning theory. These indicators were selected based on their relevance to measuring attention allocation and cognitive effort during conceptual learning tasks.

- 1 Eye movement behaviour metrics: In accordance with the conceptual learning framework, the four fundamental elements – definition, feature, category, and attribute – were each designated as areas of interest (AOIs) within the instructional video, alongside additional AOIs created based on visually highlighted content to better capture learners' attention. Two key eye movement metrics were selected for analysis: fixation duration, which represents the total time a learner's gaze remains within a specific AOI and is positively correlated with cognitive load and information complexity, thereby serving as an indicator of mental effort and depth of information processing; and visit count (also referred to as fixation count), which measures the frequency of gaze fixations on a given AOI and reflects the degree of attention or cognitive demand associated with specific content segments. The operational definitions and interpretations of these metrics are presented in Table 1.

Table 1 Definition and explanation of eye movement indicators

<i>Eye movement index</i>	<i>Definition</i>	<i>Explanation</i>
Fixation duration	Sum of gaze time for all AOI	The fixation time is the duration of a human eye's focus on a fixation point. The average value is important and commonly used to analyse eye movement characteristics. The average fixation time is positively correlated with the complexity of the information and the difficulty of the task, and the longer the average fixation time, the more the cognitive effort exerted by the viewer.
Visit count	Number of fixation points in AOI	Fixation is the relatively static state between two saccades in the process of reading or visual searching, and the more the number of fixation points, the more the attention paid to the material or the greater the cognitive load of the viewer.

- 2 Test scores: To complement the eye-tracking data and evaluate learning outcomes, this study employed a post-video knowledge test comprising ten items designed to measure both retained knowledge and transferable knowledge. Specifically, six items focused on factual recall from the video content, while four items assessed learners' ability to apply and process the acquired information in new contexts. Prior to the main experiment, the test was piloted with 89 students of diverse academic backgrounds, including various genders and majors, to ensure its validity and reliability. The results demonstrated good usability of the assessment tool, with an average test score of 43 out of 100 and a normal distribution pattern, indicating its appropriateness for subsequent statistical analysis.

4 Results

4.1 Distribution of learner's attention to four elements of concept (i.e., name, definition, attribute and example)

The four elements of concept learning, name, definition, attribute and example, are divided into four AOI: AOI_n, AOI_d, AOI_a and AOI_e. The mean and standard deviation of the fixation time and average access time are calculated, and the results are shown in Table 2. The results show that in their learning process, the learners paid little attention to the four main elements of concept learning. The average values reveal that the learners paid little attention to the four AOI. The learners paid the most attention to the attribute name, compared with the three other elements, and the standard deviation of the four attributes ranges from 0.07 to 0.14. In addition, the learners paid little attention to the four main elements. In terms of the average access time, the learner's access time for the concept name and case is short, but their access time for the concept definition and attribute is long, and the standard deviation is between 1.38 and 6.58. The results indicate that the learner's access time for the concept case is relatively consistent, and the time difference in the participants' access time for the concept attribute is relatively large. A scatter diagram of the standard deviation of attention paid to the four elements is presented in Figure 2.

Table 2 Standard deviation of mean fixation time and mean access time for different AOI

<i>AOI</i>	<i>Mean fixation time</i>	<i>Average access time</i>
AOI _n	0.337 ± 0.14	1.852 ± 1.60
AOI _d	0.305 ± 0.09	14.30 ± 5.15
AOI _a	0.301 ± 0.07	12.19 ± 6.58
AOI _e	0.289 ± 0.11	2.16 ± 1.38

4.2 Analysis of learner's eye movement in key parts (information marked in red, highlighted and so on)

Two key video content (information marked in red in the video) are selected and divided into AOI, namely, AOI₁ and AOI₂. The distribution of the learner's attention to the two AOI is calculated, and the results are shown in Table 3. In Table 3, the ratio of the fixation time for the AOI to the total focus time and the ratio of the access time for the AOI to the total focus time for the two key content marked in red are greater than the ratio of the AOI to the total focus area. The results indicate that the learners paid more attention to the marked content than to the general content based on the focus time for the AOI. By contrast, the access time for the AOI is relatively short, which indicates that the key parts of the video (information marked in red, highlighted and so on) attracted the attention of the learners.

Figure 2 Scatter plot of standard deviation of attention paid to four elements of concept

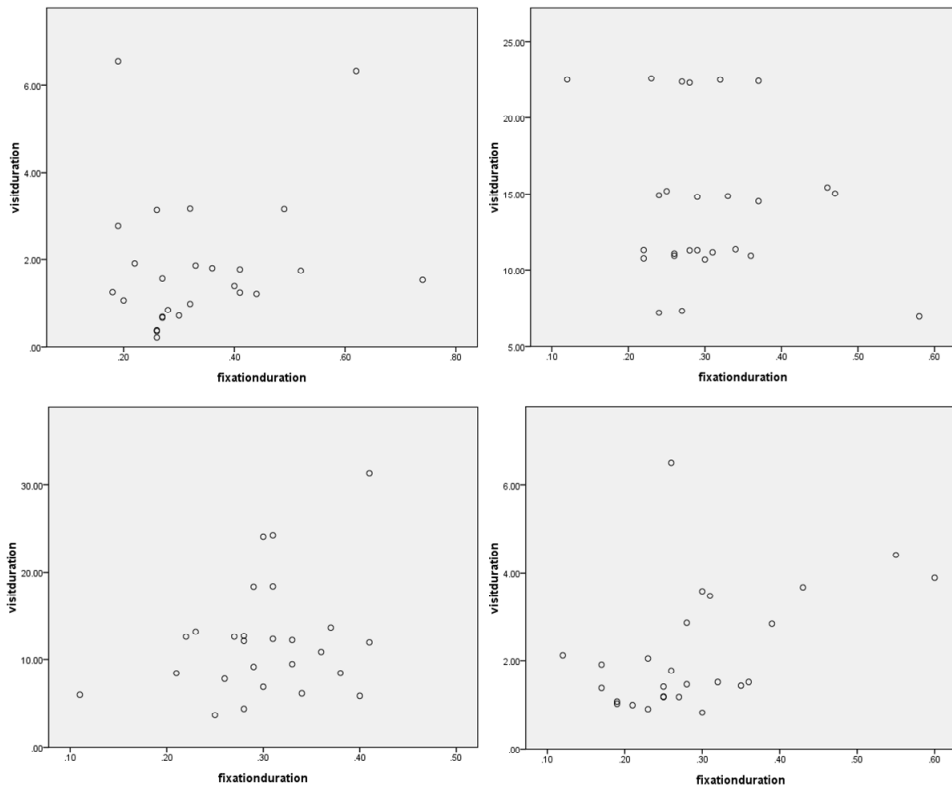


Table 3 Distribution of learner's attention to two AOI

AOI	AOI fixation time/total fixation time	AOI access time/total focus time	AOI/total area of gaze
AOI ₁	0.87	0.0215	0.018
AOI ₂	0.96	0.034	0.015

4.3 Correlation between attention and test score

The participants are divided into two groups based on their test score (the scores of the high-test-score group range from 80 to 100, and the scores of the low-test-score group are lower than 80), with 13 participants in each group. An independent samples T-test is performed to analyse the differences between the visual attention patterns of the two groups. The test results are presented in Table 4. Firstly, a positive test is conducted on the data, and the results show that the data conform to a positive distribution. Secondly, correlation analysis is conducted, and the results indicate that the correlation coefficient between the visit duration mean (attribute) and test score is 0.489, and $|r| = 0.489$. Thus, the visit duration mean (attribute) and achievement demonstrate moderate correlation. The significance value of the other variables is greater than 0.05, that is, the P-value is less than 0.05, which indicates that no significant correlation exists between the variables

and achievement. In other words, no significant differences exist in the eye movement index between the learners in the high- and low-test-score groups.

Table 4 Analysis of correlation between attention and performance

<i>Index</i>	<i>Correlation</i>	<i>Significance</i>
Fixation duration N (name)	−0.057	0.784
Fixation duration mean (name)	0.081	0.694
Visit duration N (name)	0.289	0.152
Visit duration mean (name)	0.063	0.761
Fixation duration N (definition)	0.288	0.153
Fixation duration mean (definition)	−0.188	0.359
Visit duration N (definition)	−0.243	0.232
Visit duration mean (definition)	0.280	0.165
Fixation duration N (attribute)	0.243	0.231
Fixation duration mean (attribute)	−0.124	0.546
Visit duration N (attribute)	−0.327	0.102
Visit duration mean (attribute)	0.489*	0.011
Fixation duration N (example)	−0.002	0.992
Fixation duration mean (example)	−0.008	0.970
Visit duration N (example)	−0.032	0.875
Visit duration mean (example)	−0.146	0.478

4.4 Gender differences in fixation time

Table 5 shows the average fixation time of the participants of different genders for the different AOI. An independent samples T-test is conducted on the eye movement data, and the significance values are all higher than 0.05. Therefore, no significant differences exist in the fixation time between the two genders; that is, no significant differences exist in the average fixation time between the male and the female participants.

Table 5 Comparison of mean fixation time between gender groups

<i>Areas of interest</i> <i>Analysis</i>	<i>Fixation duration (mean fixation time)</i>				<i>Visit duration (average access time)</i>			
	<i>AOI_n</i>	<i>AOI_d</i>	<i>AOI_a</i>	<i>AOI_e</i>	<i>AOI_n</i>	<i>AOI_d</i>	<i>AOI_a</i>	<i>AOI_e</i>
F	0.336	1.624	1.039	6.008	0.771	0.001	0.003	2.959
Correlation	0.370	0.131	0.516	0.596	0.837	0.879	0.904	0.241

5 Discussion

This study explored the visual attention distribution and learning performance of learners when engaging with conceptual knowledge through instructional videos, using eye-tracking technology. Several key findings emerged, which provide insights into both

the cognitive processing of learners and the instructional design of concept-based video materials.

First, the relatively balanced distribution of attention across the four elements of conceptual knowledge – name, definition, attribute, and example – suggests that learners processed the information in a structurally consistent manner. The low standard deviations of fixation and access time across these elements (ranging from 0.07 to 0.14) imply that learners were able to engage evenly with each conceptual component, potentially due to the clear structuring of the video content. This finding aligns with Ausubel's theory of meaningful learning, which emphasises the importance of presenting conceptual knowledge in an organised format to facilitate assimilation (Bryce and Blown, 2024). Thus, structuring videos explicitly around these four conceptual elements may reduce cognitive load and enhance learners comprehension.

Second, the study revealed that visual cues – such as highlighted or red-marked content – effectively directed learner attention. Eye-tracking data demonstrated that these highlighted areas received significantly more fixation time and attention allocation than non-highlighted regions. This result supports prior research, such as Jian and Abubakar (2024), which found that signalling elements in multimedia learning (e.g., colour or emphasis) can enhance memory and comprehension. However, this finding contrasts with Chen et al. (2024), who reported that arrow cues did not significantly improve attention or knowledge transfer. One possible explanation for this discrepancy may lie in the nature of the cueing strategy; while simple directional cues may be insufficient, colour and visual emphasis could foster deeper cognitive processing by drawing attention to semantically relevant content (Hardman et al., 2020).

Third, although learners were clearly drawn to highlighted content, no strong correlation was found between visual attention and test performance, except for a moderate correlation in visit duration on the 'attribute' element ($r = 0.489$, $p < 0.05$). This suggests that attention alone does not guarantee learning success, which aligns with findings by Pérez-Rúa et al. (2020), who indicated that attention guidance in videos may not always translate into performance improvement. This could be due to the relatively simple nature of declarative knowledge in the test, or to the limited discriminative power of the test items themselves. Fatima et al. (2021) noted, cognitive engagement does not always equate to deep understanding unless it is paired with active processing and integration of knowledge.

Fourth, the lack of significant gender differences in fixation time across the four AOIs indicates similar cognitive processing strategies between male and female learners in the context of conceptual video learning. This contrasts with Jian and Abubakar (2024), who reported that female learners may expend more cognitive effort during media learning. The divergence in findings may result from differences in task complexity, domain content, or the medium of information presentation. In our study, the uniform structure and limited duration of the video may have equalised cognitive demand across genders.

Taken together, the findings suggest that well-structured concept videos, especially those incorporating visually emphasised elements, can enhance learner attention. However, visual attention does not directly translate to learning achievement unless supported by deeper cognitive engagement and high-quality assessment design. These insights contribute to the broader literature on multimedia learning and provide practical implications for the instructional design of online video resources.

6 Conclusions

This study draws several conclusions.

- 1 In the concept learning video, the distribution of the attention to the four elements of a concept (i.e., name, definition, attribute and example) is relatively average and stable.
- 2 The key parts of the video (information marked in red, highlighted and so on) attracted the learner's attention.
- 3 No significant differences exist in the eye movement index between the learners in the high- and low-test-score groups.
- 4 No significant differences exist in the average fixation time between the male and the female participants.

Therefore, conceptual knowledge videos should be designed in accordance with the four elements of concept learning. Moreover, comprehensive and different concept-related examples should be provided in such videos, and the features and characteristics of the examples should be visually highlighted individually and listed clearly, with icons or blackboard scripts. Common or key features should be extracted through dynamic processes, such as real-time drawing and explanation, and emphasised through the use of words and language appropriate to the students' cognitive level. Moreover, conceptual video design should focus on presenting the four elements of a concept, providing multiple examples and highlighting the key points in the examples to help learners remember the information and understand the common attributes and features defined in the video by analysing the examples. Therefore, conceptual video design should consider the use of relevant prominent markings, dynamic effects or production effects.

In designing and producing online video courses, many educational practitioners rely on experience, rather than empirical research on the factors that can affect the effectiveness of video learning. In this study, conceptual knowledge learning involves declarative knowledge learning, and the actual online video learning process is simulated in the experiment process design. Therefore, the conclusions have considerable guidance value to conceptual knowledge video design. This study has some shortcomings owing to the limitations of the experiment conditions. In terms of the online video learning process, this study clarifies that certain limitations exist owing to the various factors that must be controlled in the eye movement experiment. In addition, limitations exist in the objective conditions, and the sample size is not adequately large. Follow-up studies should collect additional sample data based on the results of the eye movement experiment conducted in this study for comprehensive analysis.

Acknowledgements

This study was financially supported by a Guangdong Polytechnic Normal University Graduate Innovation Project (2023YGSY05009) and Guangdong Philosophy and Social Sciences Planning Youth Project (GD23YJY16). We express our appreciation to the students who participated in the study, at the same time we would also like to thank the reviewers who gave us valuable advice.

References

- Bryce, T.G.K. and Blown, E.J. (2024) 'Ausubel's meaningful learning re-visited', *Current Psychology*, Vol. 43, No. 2, pp.4579–4598, <https://doi.org/10.1007/s12144-023-04440-4>.
- Chen, X. and Zhang, D. (2019) 'Model construction and psychological representation mechanism of declarative knowledge', *Journal of Qiqihar University (Natural Science Edition)*, Vol. 35, No. 6, pp.73–76, p.92.
- Chen, Q., Wu, Z., Liu, Y., Han, L., Li, Z., Kan, G.L. and Fan, M. (2024) 'Silver cycling: exploring the impact of bike-based locomotion on spatial orientation for older adults in VR', *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, Vol. 8, No. 3, pp.1–24, <https://doi.org/10.1145/3643726>.
- Fatima, S., Kumari, K., Sandhu, Y. and Abbas, J. (2021) 'Validation of the students' cognitive engagement measure: evidence from university students of Karachi', *Pakistan Business Review*, Vol. 23, No. 3, pp.609–620, <https://doi.org/10.22555/pbr.v23i3.609>.
- Hardman, A., Töllner, T. and Martinovic, J. (2020) 'Neural differences between chromatic- and luminance-driven attentional salience in visual search', *Journal of Vision*, Vol. 20, No. 3, Article 5, <https://doi.org/10.1167/jov.20.3.5>.
- Huang, G. (2022) *Research on Electromagnetics Concept Learning for Sophomore High School Students Oriented towards Deep Learning*, Master's thesis, Central China Normal University.
- Jia, J-G., Zhang, W-Y. and Zhang, Y. (2024) *Design and Application of Virtual Simulation System in Geophysical Experiment Teaching*, Laboratory Research and Exploration, Advance Online Publication.
- Jian, Y. and Abubakar, J. (2024) 'Comparing cognitive load in learning spatial ability: immersive learning environment vs. digital learning media', *Discover Sustainability*, Vol. 5, Article 111, <https://doi.org/10.1007/s43621-024-00310-6>.
- Liu, Y., Hu, B., Yin, X. et al. (2021) 'How can virtual reality (VR) immersive environments enable deep oriented learning engagement? Study on learning effect in complex task context', *Journal of Distance Education*, Vol. 39, No. 4, pp.72–82.
- Lu, T. and Yang, X. (2016) 'Research on the influence of information presentation style and cognitive style on mobile learning of conceptual knowledge', *China Distance Education*, No. 6, pp.36–43, p.80.
- Mayer, R.E. (2005) 'The Cambridge handbook of multimedia learning: principles for reducing extraneous processing in multimedia learning: coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles', *Information Design Journal*, Vol. 16, No. 1, pp.81–83.
- Mayer, R.E. and Chandler, P. (2001) 'When learning is just a click away: does simple user interaction foster deeper understanding of multimedia messages?', *Journal of Educational Psychology*, Vol. 93, No. 2, pp.390–397, <https://doi.org/10.1037/0022-0663.93.2.390>.
- Ozcelik, E., Arslan-Ari, I. and Cagiltay, K. (2010) 'Why does signaling enhance multimedia learning? Evidence from eye movements', *Computers in Human Behavior*, Vol. 26, No. 1, pp.110–117, <https://doi.org/10.1016/j.chb.2009.09.006>.
- Pérez-Rúa, J.M., Martinez, B., Zhu, X., Toisoul, A., Escorcía, V. and Xiang, T. (2020) *Knowing What, Where and When to Look: Efficient Video Action Modeling with Attention*, arXiv preprint, arXiv:2004.01278, <https://doi.org/10.48550/arXiv.2004.01278>.
- Pi, Z., Hong, J. and Yang, J. (2017) 'Effects of the instructor's pointing gestures on learning performance in video lectures', *British Journal of Educational Technology*, Vol. 48, No. 4, pp.1020–1029, <https://doi.org/10.1111/bjet.12471>.
- Su, C. (2022) *The Impact of Example Feedback on Concept Learning*, Master's thesis, Zhejiang Normal University.
- Wang, H., Hu, W. and Pi, Z. (2018) 'A study on the influence of teacher behavior on the learning effect of teaching video', *Journal of Distance Education*, Vol. 36, No. 5, pp.103–112.

- Wang, H., Pi, Z. and Hu, W. (2019a) 'The instructor's gaze guidance in video lectures improves learning', *Journal of Computer Assisted Learning*, Vol. 35, No. 1, pp.42–50, <https://doi.org/10.1111/jcal.12309>.
- Wang, H., Pi, Z. and Huang, X. (2019b) 'The influence of cue types on learning outcomes in digital learning resources', *China Distance Education*, No. 9, pp.43–52, p.92.
- Wang, Y., Zhang, H. and Wang, Y. (2020) 'The impact of instructional video on conceptual knowledge learning: a comparison of the difference between physical video and animated video', *Modern Educational Technology*, Vol. 30, No. 5, pp.40–46.
- Xie, Y., Yang, J. and Pi, Z. (2021) 'Research on the influence of pre-embedded questions and feedback on learning in teaching video', *China Distance Education*, No. 12, pp.63–71, p.77.
- Yang, J. (2023) *Design Research of Concept-based Teaching*, Master's thesis, East China Normal University.