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Effects of Two-Tier Self-Explanation and Attention Cueing Strategy on the Learning Achievement in Distance Multimedia Learning

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Distance learning becomes the new trend of development. When learners conduct distance learning, the features and the free status of distance learning make it easy for students to become distracted or unfocused in their learning. Therefore, design a material with cues based on "Central Cue" and "Peripheral Cue" from "Attentional Cuing Paradigm" to explore two cues that represent "endogenous" and "exogenous" attentional cueing by using multimedia video learning, to check whether it can effectively enhance the focus on the target area of interest (AOI) and the impact of the learning achievements and varieties. Detect learners' eye movements and patterns by an eye tracker to analyze the relationship between learners' watching patterns and learning achievements. In addition, we use two-tier testing combined with self-explanation prompts for design, including the menu-based self-explanation strategy on the first level and the open-ended self-explanation strategy on the second level. Explore whether the two-tier self-explanation strategy will have better self-explanation learning achievements than the single-tier self-explanation strategy or not. The results show that learners using the central cue representing endogenous attentional cueing can effectively focus on the target AOI. The two-tier self-explanation strategy can help learners improve their learning achievement, learning motivation, and reflection.

Keywords: cueing, self-explanation, two-tier, multimedia distance learning, eye-tracking

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INTRODUCTION

Distance learning has become a new trend of learning. Distance learning enables learners to learn anytime and anywhere according to their plans without being limited by time or space. But also because of the characteristics of learning and degrees of freedom, students cannot engage like in the actual classroom (Yueh, 2000), and can get easily distracted and unfocused. Therefore, how to enable students to focus on the content of the material is a challenge for e-learning.

Attention is not enough to confirm whether students have noticed the areas that should and need to be paid attention to in the material, and the time and location of watching affect learners' understanding and effectiveness (Tsai and She, 2006; De Koning et al., 2010a,b; Ozcelik et al., 2010; Jamet, 2014). Many researches have designed attentional cues in multimedia materials to assist

students to watch important learning information and position in the materials at the appropriate time and confirmed that attentional cues can effectively guide students' attention to the target AOI (De Koning et al., 2009, 2010a,b; Liao, 2009; Ozcelik et al., 2009), reduce irrelevant visual search to improve learning outcomes (De Koning et al., 2007, 2010a,b; Jamet et al., 2008; Amadieu et al., 2011; Lin and Atkinson, 2011), and reduce their mental load to make learning more efficient (Mayer, 2009). Based on the spatial concept, Posner (1980) proposed the "Attentional Cuing Paradigm" to explore the influence of two types of cues on attention and pointed out that attention would accelerate the reaction time to the target object if it was attracted by a stimulus. This study according to the two cues suggested by this paradigm, "central cues" and "peripheral cues," design attention cues and explore the use of two different attention cues in multimedia video learning to increase attention on the target area of interest, and the impact on learning achievement.

On the other hand, scholars found that, by guiding learners' attention to the target area of interest, learners' knowledge construction cannot be improved enough. In other words, attention selection and information extraction in the perceptual process do not equal understanding in the cognitive process (Kriz and Hegarty, 2007; De Koning et al., 2009, 2010a,b). Therefore, some scholars began to use self-explanation prompts to assist with attentional cues and to further improve the learning achievement (De Koning et al., 2011; Lin et al., 2016).

To increase the learning depth, this study will combine self-explanation prompts and a two-tier test, as an experimental factor to explore the learning outcomes in the multimedia environment. A two-tier test is considered an effective test to understand students' prior knowledge or misunderstanding (Treagust, 1988; Odom and Barrow, 1995; Tsai, 2003). We use two-tier self-explanation prompts to design our experiment, using contrapositive logic which means "if is in p, then it must be in q; else is not within q, cannot be within p," so that learners can ruminate on theira nswers from single-tier and two-tier questions, and help them think and learn deeply to make sure of their answers firmly. In this study, we may explore whether the two-tier self-explanation prompts will have better learning achievements than the single-tier self-explanation prompts.

Based on the background and motivation, this study will combine the eye-tracking technology to build a combination of attention cues and a two-tier explanation prompt of the multimedia video learning system, exploring the effect of central cues representing endogenous and peripheral cues representing exogenous on guiding learners' attention and their relationship with learning outcomes. In addition, we explore whether the two-tier self-explanation prompts derived from the two-tier test can improve learners' learning depth and effectiveness, increase knowledge construction in the learning process, and explore the relationship between cognitive load and learning effectiveness. Accordingly, the following research questions are investigated.

1. What is the effect of using two different attention cues on learners' learning performance?
2. What is the effect of using two different attention cues on their attention on the AOI?
3. What is the effect of using two different self-explanation prompts on learners' learning performance?
4. What is the effect of using two different self-explanation prompts on learners' learning motivation and reflection?
5. What are the effects of two different self-explanation prompts on the behavior pattern of the position, duration time and frequency of learners' gaze and regression, answer and change the answer, and its influence on learning performance?
6. What is the relationship between cognitive load, attention, and learning performance of two-tier self-explanation learners?

LITERATURE REVIEW

Cueing

Based on the spatial concept, Posner (1980) proposed the "Attentional Cuing Paradigm" to explore the influences of central cues and peripheral cues on attention and pointed out that attention would accelerate the reaction time to the target object if it was attracted by a stimulus (Zhang, 2017).

The central cue which causes endogenous attention cues suggests that participants will be independent and actively control the transfer of attention (Jonides, 1981). The classic central cues, such as arrows, can direct the attention to a certain place, and when the target appears in the expected spatial position, the required reaction time is faster than that of the unexpected spatial position (Posner et al., 1980).

Peripheral cues are cues that lead to exogenous attention shifts. Studies have found that two major types of stimulus will grab attention in principle—feature singleton and abrupt visual onset/offset. Feature singleton refers to a stimulus with a distinctive visual feature, such as the red dot of a group of green dots. Abrupt visual onsets/offset refers to a sudden stimulus or sudden disappearance in the field of vision (Remington et al., 1992; Gibson, 1996; Yantis and Jonides, 1996).

In the cues guidance research of multimedia materials, rare in view of the "central cue" and "peripheral cues" two categories, so this study will explore central cues representing endogenous cues and peripheral cues representing exogenous cues to the impact of multimedia learning.

Self-Explanation Prompts

Self-explanation is proposed by Chi et al. (1989). It refers to people who can explain what they are doing or what they are thinking at the moment while reading articles or solving problems (De Leeuw and Chi, 2003) or the inference that the narration clarifies or adds sentences (Chi et al., 1989).

Self-explanation is regarded as an activity that can increase learning depth and intensify learning Chi et al. (1989, 1994) argue that the learners explain themselves through reflection by promoting the integration of prior knowledge and new information, and when they explain themselves, they can find out their possible gaps in current knowledge and fill it. This process can produce a better quality of descriptive knowledge (VanLehn et al., 1992). Many studies have also pointed out that reflection plays an important role in the construction of knowledge and contributes to the improvement of the learning performance

(Leijen et al., 2009; Quinton and Smallbone, 2010). The effect of self-explanation can be explained by two basic inference mechanisms: inference generation, in which learners learn the differences between their mental models and new information and try to deduce the new knowledge from the inference they have made from the inference. The other is conceptual revision, which means that when learners learn explanatory texts, they will find the conflict between the defective mental model and the text, and they will consciously try to solve the dissonance (Chi et al., 1994; Chi, 2000; Kwon et al., 2011).

Chi and Wylie (2014) divided self-explanation into five types according to the form of self-explanation tips: open-ended: learners can freely explain content from the overall point of view; Focused: focused on interpreting specific content within a certain scope; Scaffolded: similar to fill in the blank questions, learners need to fill in their answers; Resource-based: learners can make use of the materials or resources provided for an explanation; Menu-based: similar to a choice question, select the answer from the options.

De Koning et al. (2010a) indicate that when learning the animation material, the attention cues may help learners focus on the important part, but not necessarily can improve grades. In other words, attention selection and information extraction in the perceptual process do not equal understanding in the cognitive process. Therefore, some scholars began to use self-explanation prompts to assist attentional cues. By actively processing information, learners can increase the cognitive process of content to improve learning efficiency.

For example, De Koning et al. (2011) explored whether cardiovascular animation combined with self-explanation and cues learning strategies could generate necessary cognitive activities in learning. The results showed that using cues and self-explanation learning strategies in animation learning could improve learners' learning outcomes.

Two-Tier Test

A two-tier test is considered an effective test to understand students' knowledge, misunderstanding, or other concepts (Treagust, 1988; Odom and Barrow, 1995; Tsai and Chou, 2002; Tsai, 2003; Chou et al., 2007; Li et al., 2021; Hwang et al., 2022). The two-tier test is a two-level multiple-choice question. In the first level, students' descriptive or factual knowledge is evaluated, while in the second level, students' reasons for choosing in the first level and their in-depth explanation of factual knowledge are explored (Yang et al., 2015). Since it can understand why students have such wrong ideas and concepts, for teachers, a two-tier test can be useful to deeply understand students' wrong ideas and concepts (Chu et al., 2010).

Chu et al. (2010) proposed the two-tier location-aware mobile learning system in a science course, which proved that the system could improve students' learning achievement and motivation. In addition, Yang et al. (2015) explored the effect of using two-tier tests on learning performance and behavior patterns in programming learning and proved that two-tier tests can indeed improve students' programming skills.

Therefore, this study will combine the eye-tracking technology to establish a multimedia learning system that combines attention cues and two-tier self-explanation prompts, and explores the influence of the central cues representing endogenous cues and peripheral cues representing exogenous cues on guiding learners' attention and learning outcomes. The eye tracker will be used to record and analyze the learner's attention distribution.

RESEARCH METHODS

Development of a Multimedia Video Learning System That Combines Attention Cues With Two-Tier Self-Explanation Prompts

The purpose of this study is to establish a multimedia video learning system that combines attention cues with two-tier self-explanation prompts and to explore the effect of central cues representing endogenous and peripheral cues representing exogenous in guiding learners' attention and their relationship with learning outcomes. In addition, this study explored whether two-tier self-explanation prompts based on a two-tier test could improve learners' learning depth and effectiveness, increase knowledge construction in the learning process, and explore the relationship between cognitive load and learning performances. The multimedia learning environment combining attention cues and two-tier self-explanation prompts is shown in **Figure 1**. After calibration of the eye tracker in the computer classroom, learners will learn the video materials and test questions from the operating system subject stored in the back-end database through the multimedia learning system combined with attention cues and self-explanation prompts. During the learning process, the eye tracker will record the learners' eye movement behaviors at any time, and send the measured values, learners' behavior patterns, and test results to the back-end database module to record the learning process for analysis and use.

In this study, the multimedia learning system with the combination of two-tier self-explanation and attentional cues, functions, and system images were introduced as follows: The system will record learners' current learning attention level by the eye tracker, visual search, gaze and regression position, frequency, and duration time. After the experiment, it will further analyze its influence on learning performance and learning behavior pattern analysis.

Attention-guided cues of this study are shown in **Figures 2**, **3**. According to the experimental group, we divided the two different attention-guided experimental factors into "central cue" representing endogenous and "peripheral cue" representing exogenous and explored the relationship between the two factors in guiding attention to the target AOI and learning performance. The central cue will dynamically guide learners' attention with the mouse indicator (red arrow in **Figure 2**), so that learners can autonomously and actively cause endogenous attention diversion. Peripheral cues highlight the key points of learning with distinctive red color and bottom line (Theeuwes, 1991, 1992; Joseph and Optican, 1996), and dynamically present the text content, so that the key points can be highlighted and the learners' attention can be shifted (as shown in **Figure 3**).

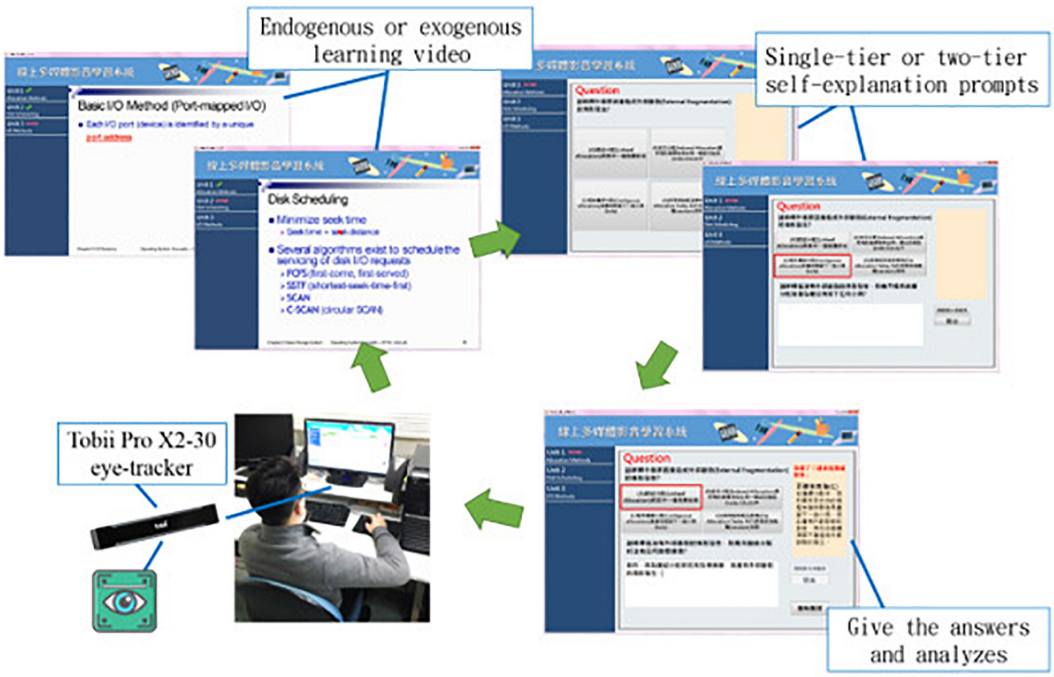

FIGURE 1 | Eye-tracking multimedia learning environment.

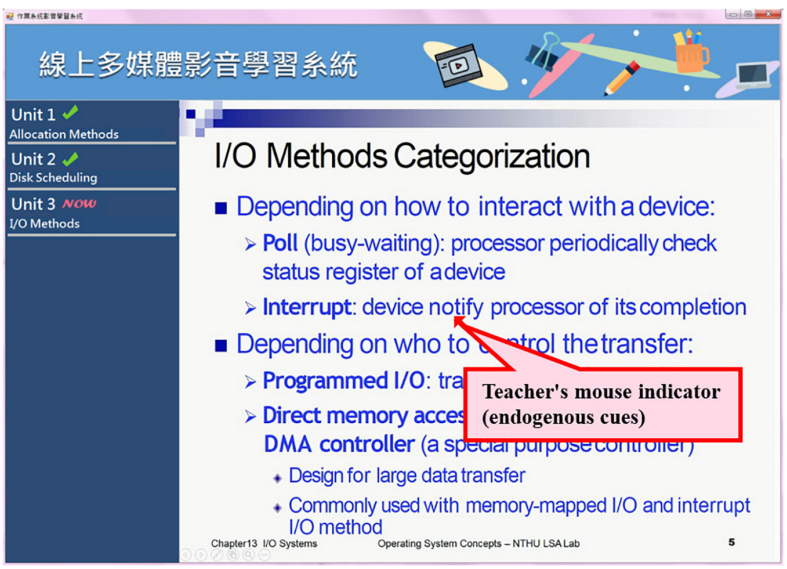

FIGURE 2 | Central cues representing endogenous.

Single-tier and two-tier self-explanation prompts: According to the self-explanation prompts of single-tier and two-tier in the experimental group, we explored the influence and difference between single-tier and two-tier self-explanation on learning outcomes. Single-tier self-explanation only includes multiple-choice self-explanation questions, which are single-choice questions with four options and a correct answer. In addition to the single-choice self-explanation questions of the first level, there will be four different second-level questions for the choices of the first level, meaning that the questions of the second level will be different according to the choices of the first level (as shown in **Figure 4**). We design our questions by using contrapositive logic, which means "if is in p, then it must be in q; else is not within q, cannot be within p," so that learners can ruminate their answers from single-tier and two-tier questions and help them think and learn deeply to make

sure of their answers firmly. In addition, using sequence analysis to explore the learner's eye movement in learning activities include duration time, frequency and location of gaze, answer and change the answers, and explore their learning behavior and their relationship with learning performances.

The menu-based self-explanation and whether the answer is correct or not will give different feedback. If the answer is correct, then you can continue to play the video (as shown in **Figure 4**). If the answer is wrong, it will be analyzed and the correspondent video paragraph must be reviewed again before moving to the next video paragraph. Video cannot be freely controlled by students, and students need to complete all course films to pass the learning standards.

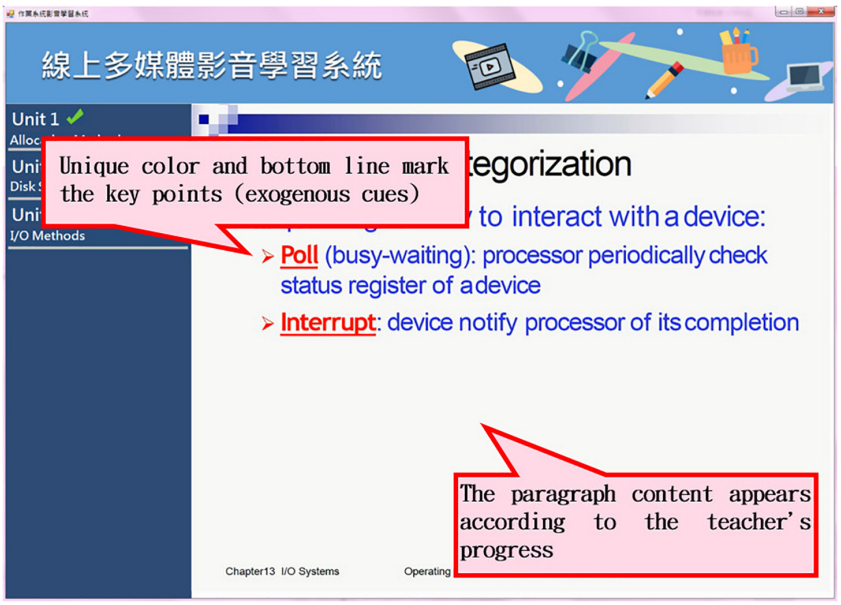

FIGURE 3 | Peripheral cues representing exogenous.

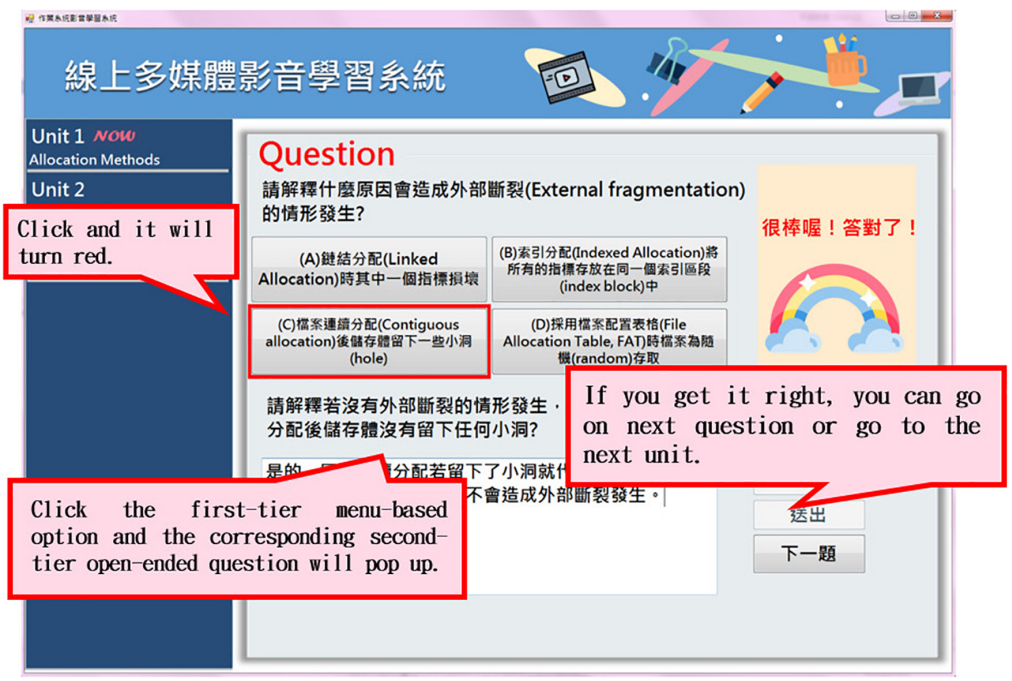

FIGURE 4 | Quiz function and correct answer.

Experimental Design

The first independent variable is the attention cue (endogenous and exogenous). The second independent variable is the self-explanation prompt (single-tier group and two-tier group). The dependent items of this study were learning performances, learning motivation, reflection, attention distribution, and learning behavior patterns.

Participants

The subjects of this study were 84 students, 42 boys and 42 girls, who have completed the operating system course from a university in Taipei. The average age is 21 years. According to the different attention cues and self-explanation prompts, they are divided into three groups, respectively, which are "endogenous single-tier group," "endogenous two-tier group," and "exogenous two-tier group," with 28 each.

Experimental Procedure

The purpose of this study was to investigate the effect of two-tier self-explanation prompts (two-tier self-explanation/single-tier self-explanation) and attentional cues (endogenous cue/exogenous cue) on the effectiveness of multimedia learning. The learning process is shown in **Figure 5**.

To verify the effectiveness of this study and to understand the effects of attention cues and two-tier self-explanation prompts on learners, the activity design of materials was carried out by using the undergraduate operating system course. Experimenters are divided into three groups in two variables to explore the effects of attention cues and two-tier self-explanation prompts on learners. Before learning activities, learners are required to complete a pre-test and questionnaire, which include learning motivation and reflection and do the eye movement calibration. Then, according to different teaching strategies, they can be divided into three groups for experiments. During learning, the eye tracker will record the gaze duration time, frequency and position to confirm the effect of attention cues, and the learning behavior sequence of self-explanation. The relationship between these two learning strategies and learning outcomes was confirmed by post-test. Finally, questionnaires were used to confirm learners' learning motivation, reflection, and cognitive load.

Research Tool

Several instruments were utilized in the experiment, including a video, a pre-test, a post-test, and nine interview questions.

The course of this study is the Operating system, and the multimedia materials is based on the teaching video of professor

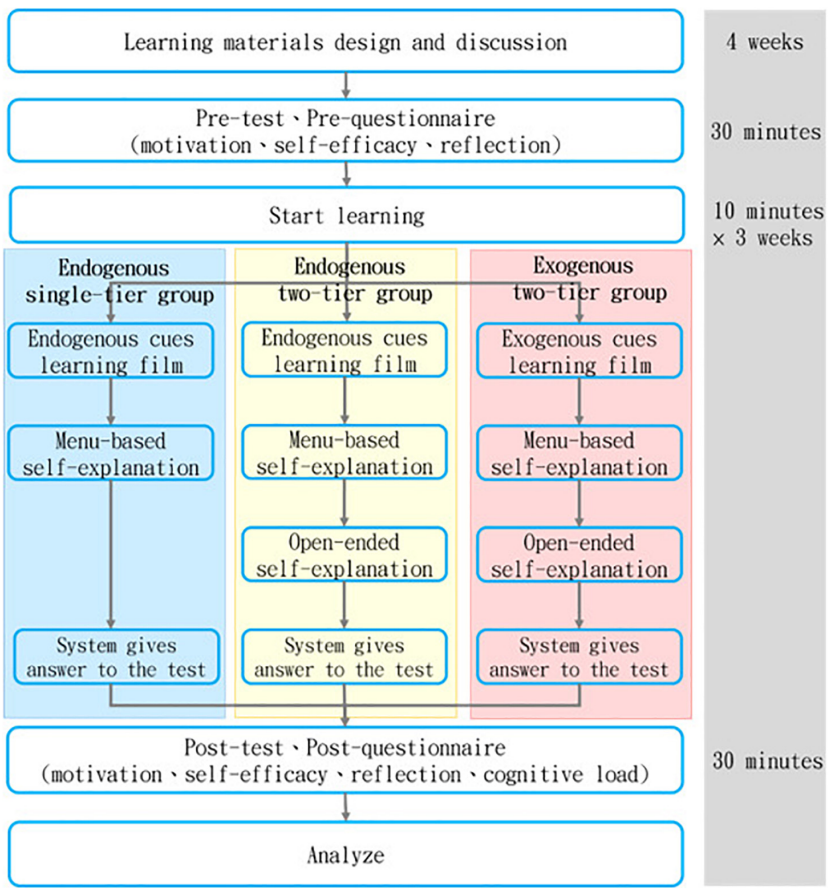

FIGURE 5 | Learning process.

Zhi-Yuan Zhou in the open online course of National Tsing Hua University. Three units are selected as the study objectives, which are "Allocation Methods," "Disk Scheduling," and "I/O Methods."

The study learning performance test includes pre-test and post-test, containing 20 multiple-choice questions with 5 points for each question and 100 points in total. The pre-test content for the operating system does not contain the unit of learning goals. To understand the three groups of learners in the experiment, prior knowledge of the operating system course is needed, if there is a difference. The content of the post-test is the unit content of this learning video and to analyze whether learners' learning performances are different when using different attention cues and self-explanation prompts.

This learning motivation questionnaire cited Wang and Chen (2010) adapted from the motivation questionnaire proposed by Pintrich et al. (1991). The main content of this paper is to discuss the motivation of operating system before and after learning activities. The pre-questionnaire and post-questionnaire were the same, with a total of four questions. The Likert 5-point scale was used, and Cronbach's alpha were 0.91 and 0.90.

The reflection questionnaire was adapted from the reflection questionnaire proposed by Kember et al. (2000). The main content of this paper is to discuss the reflection before and after learning activities. A total of four questions were used. The Likert 5-point scale was used. The Cronbach's alpha before and after the questionnaire was 0.90 and 0.85.

The cognitive load questionnaire quoted by Hwang et al. (2013) was adapted from the cognitive load questionnaire proposed by Paas (1992). The questionnaire is divided into mental load and mental effort. The mental load is the study of learning whether the difficulty of the teaching material is a load to the learner, with a total of three questions, using the Likert 7-point scale, and Cronbach's alpha 0.8. The mental effort is to explore the content of the teaching materials used in the learning activities and to exert a load on the learners' learning. A total of three questions were used. The Likert 7-point scale had a Cronbach's alpha of 0.83.

After completing the learning activities, the eye movement data recorded by learners in the two-tier self-explanation was coded and analyzed based on the sequential analysis method (Bakeman and Gottman, 1997) to investigate the relationship between learners' eye movement and learning behavior in self-explanation during the learning process. The eye movement data were adapted from the message coding proposed by Hou et al. (2009) to analyze the students' learning behavior during the learning process. The different kinds of behavior and an explanation of each are shown in **Tables 1**, **2**.

RESULTS

Learning Achievement

This section examines whether there are significant differences in the learners' learning performances with respect to the operating system. To understand whether the two groups of learners have the same level of operating system prior knowledge, the two groups were tested before learning activities, and the independent sample t-test was used to analyze the differences in learners' operating system competence. There was no significant difference in the average pre-test scores between the endogenous single-tier group and endogenous two-tier group and between the endogenous two-tier group and exogenous two-tier group ($t = 0.35$, $p = 0.73 > 0.05$; $t = -0.05$, $p = 0.96 > 0.05$), indicating that there was no significant difference in the operating system ability between the two groups of learners before the experiment.

After learning activities, to analyze whether there are significant differences in learning outcomes among different groups of learners, this study implemented post-tests, and the test results were analyzed with ANCOVA as the covariance. As shown in **Tables 3**, **4**, the learning performance of the endogenous two-tier group was significantly higher than the endogenous single-tier group ($F = 9.95$, $p = 0.003 < 0.01$). And the learning performance of the endogenous two-tier group and the exogenous two-tier group did not reach the significant difference level ($F = 1.25$, $p = 0.27 > 0.05$). It is concluded that the two-tier learning pattern is more effective than the single-tier learning pattern.

Analysis of the Learning Attention

This section mainly discusses two different cues to the learners' attention distribution situation. In this research, through the eye-tracker, the eye movement behavior of learners watching the materials is recorded, and the video materials can be divided into 57 AOI blocks, according to the timeline of the teacher-mentioned setting of dynamic AOI, respectively, for the endogenous two-tier group and exogenous two-tier group to compare it with the average gaze duration time and the average number of gazes. The location and time of the two groups of 57 AOI are the same.

TABLE 1 | Two-tier self-explanation behavior coding table.

Code	Behavior	Description
L1	Gaze at the first-tier question	Staring at the content of the questions and options of the first-tier questions and options
L2	Choose the answer	Selecting the self-explanation answers in the first-tier
L3	Gaze at the two-tier question	Staring at the second-tier questions
L4	Type in self-explanation text	Enter text in the second-tier self-explanation text box
R	Back to the video to review	Students go back to the video to find the answers

TABLE 2 | Single-tier self-explanation behavior coding table.

Code	Behavior	Description
L1	Gaze at the first-tier question	Staring at the content of the questions and options of the first-tier questions and options
L2	Choose the answer	Selecting the self-explanation answers in the first-tier
R	Back to the video to review	Students go back to the video to find the answers

TABLE 3 | Post-test of learners between the endogenous single-tier group and the endogenous two-tier group.

Group	*N*	Mean	SD	Adjusted mean	*F*	η^2
Endogenous single-tier	28	56.61	9.82	56.28	9.95**	0.16
Endogenous two-tier	28	61.96	9.85	62.29		

*$^{**}p < 0.01$.

TABLE 4 | Post-test of learners between the endogenous two-tier group and the exogenous two-tier group.

Group	*N*	Mean	SD	Adjusted mean	*F*	η^2
Endogenous two-tier	28	61.96	9.85	62.02	1.25	0.02
Exogenous two-tier	28	60.00	11.55	59.95		

The independent sample *t*-test results showed that the average gaze time and the number of gazes of the endogenous two-tier group were significantly higher than those of the exogenous two-tier group ($t = 2.17$, $p = 0.04 < 0.05$; $t = 4.27$, $p = 0.00 < 0.01$). In other words, learning videos that represent the type of endogenous can obtain higher gaze time and number of gazes for learners, that is, they can pay more attention to the key parts of learning materials with the teacher's teaching.

Analysis of Learning Motivation, Reflection, and Cognitive Load

The learning motivation questionnaire mainly discusses the motivation for learning before and after learner activities using the Likert 5-point scale. The analysis of the motivation of the pre-questionnaire for learning uses an independent sample *t*-test. The results showed that there was no significant difference in learning motivation between the groups before the experiment ($t = 0.83$, $p = 0.41 > 0.05$; $t = 0.15$, $p = 0.88 > 0.05$), indicating that the two groups had similar learning motivation before learning activities. The post-questionnaire of motivation was analyzed by ANCOVA and the pre-learning motivation questionnaire was used as a covariate. The results showed that the learning motivation of the endogenous two-tier group was significantly higher than that of the endogenous single-tier group. And the learning motivation of the endogenous two-tier group and the exogenous two-tier group did not reach the level of significant difference. It is concluded that the two-tier learning pattern is more helpful to enhance learners' motivation than the single-tier learning pattern.

The purpose of the reflection questionnaire is to explore the learner's tendency to self-reflection before and after learning activities. The Likert 5-point scale was used. The analysis of the reflection pre-questionnaire uses an independent sample *t*-test. The results showed that there was no significant difference between the groups ($t = 1.06$, $p = 0.30 > 0.05$; $t = -0.48$, $p = 0.63 > 0.05$), indicating that each group had the same degree of reflective tendency before learning activities. After learning activities, each group of students implements the post-questionnaire of reflection. The ANCOVA test was used for the post-questionnaire and the pre-questionnaire was used as the co-variable for the reflection post-questionnaire. The results showed that the reflection of the endogenous two-tier group was significantly higher than that of the endogenous single-tier group ($F = 9.71$, $p = 0.003 < 0.01$). And the reflection of the endogenous two-tier group and the exogenous two-tier group did not reach the significant difference level ($F = 0.07$, $p = 0.79 > 0.05$). It is concluded that the two-tier learning pattern adopted by learners in the endogenous two-tier group is more conducive to enhancing learners' reflective tendencies than that in the endogenous single-tier group.

In this study, cognitive load questionnaires were implemented for each group of students after learning activities. Cognitive load is divided into two aspects: mental workload and mental effort. The mental workload is to discuss whether the difficulty of learning materials is caused by the learner's learning. A total of three questions are used and the Likert 7-point scale is used. The mental effort is to explore the content of the materials used in learning activities, and to the extent that the learners are burdened with learning. A total of three questions are used, and the Likert 7-point scale is used. The independent sample *t*-test analysis was carried out. The results showed that the mental load and mental effort of the exogenous two-tier group were significantly higher than that of the endogenous two-tier group ($t = -2.04$, $p = 0.04 < 0.05$; $t = -2.15$, $p = 0.03 < 0.05$). However, there was no significant difference in mental load and mental effort between the endogenous single-tier group and the endogenous two-tier group ($t = 0.60$, $p = 0.55 > 0.05$; $t = -0.39$, $p = 0.70 > 0.05$). The results show that different attention cues will make learners affected by differences in the cognitive load. That is, peripheral cues representing exogenous were associated with a higher cognitive load than central cues representing endogenous.

Furthermore, the correlation analysis result is showed in **Table 5**. It mainly discusses the two-tier self-explanation of learners and their relationship between cognitive load, attention, and learning performance. The average gaze duration time of this analysis by learners represents the attention of students, the post-test represents learning performance, and the cognitive load is the average of mental effort and mental load.

The results show that there is a significant negative correlation between learners' attention and cognitive load (Pearson's correlation coefficient = −0.38, $p = 0.004 < 0.01$). It maens that the higher the learner's attention to the materials, the lower the cognitive load. In addition, the correlation between

TABLE 5 | Pearson correlation analysis between cognitive load, attention, and learning performance.

Variable	Learning performance	Attention	Cognitive load
Learning performance	1		
Attention	0.09	1	
Cognitive load	−0.18	−0.38**	1

$^{**}p < 0.01$.

learning performance and attention is not significant, which can be mutually verified by the research of De Koning et al. (2009, 2010a,b) and Liao (2009). It represents the attention selection and information extraction in the process of learners' perception, which is not necessarily equal to the understanding in the cognitive process. In other words, high attention does not necessarily mean good learning outcomes.

Sequential Analysis of Learning Behavior

This study investigates two different self-explanation prompts on learners' gaze and regression of location, time, frequency, and answering, change the answer process, and behavior patterns. Code for the main behavior that is generated includes a note in the first level questions and options (L1), select the answer (L2), pay attention to the second level question (L3), input self-explanation text (L4), and return to the film review and find the answers (R).

The code will be analyzed using GSEQ software, and get the adjusted residuals table using the *z*-score binomial probability statistics verification significantly as a result, to explain the sequence when the *z*-score value is greater than 1.96, it is significant. The significant behavior are drawn as behavior transition diagrams (shown in **Figures 6A–C**). After watching the questions of the second tier, students of the two-tier groups would then reflect on the questions of the first tier and the correctness of their answers (L3 → L1). When answering the open-ended questions of the second tier, students will return to the questions and answers of the first tier to think and answer again (L4 → L1). After watching the first-tier question and other options significantly, the students will return to the film and try to find the answer (L1 → R). After watching the film, students will go back to the first-tier questions and think about the questions and answers again (R → L1). In addition, learners in the exogenous two-tier group were more likely to return to the film to review and look for answers after paying attention to the second-level questions than those in the endogenous two-tier group (L3 → R).

Students in the single-tier group would rethink the questions and options after choosing the answers (L2 → L1) and then return to the film to review and think about the questions (R > L1). Compared with students in the two-tier groups, students in the single-tier group were less likely to go back to the film to review the answers after watching the questions and options.

Interview Analysis

To have a deeper understanding of learners' thoughts on the two-tier self-explanation prompts and attentional cues mechanism

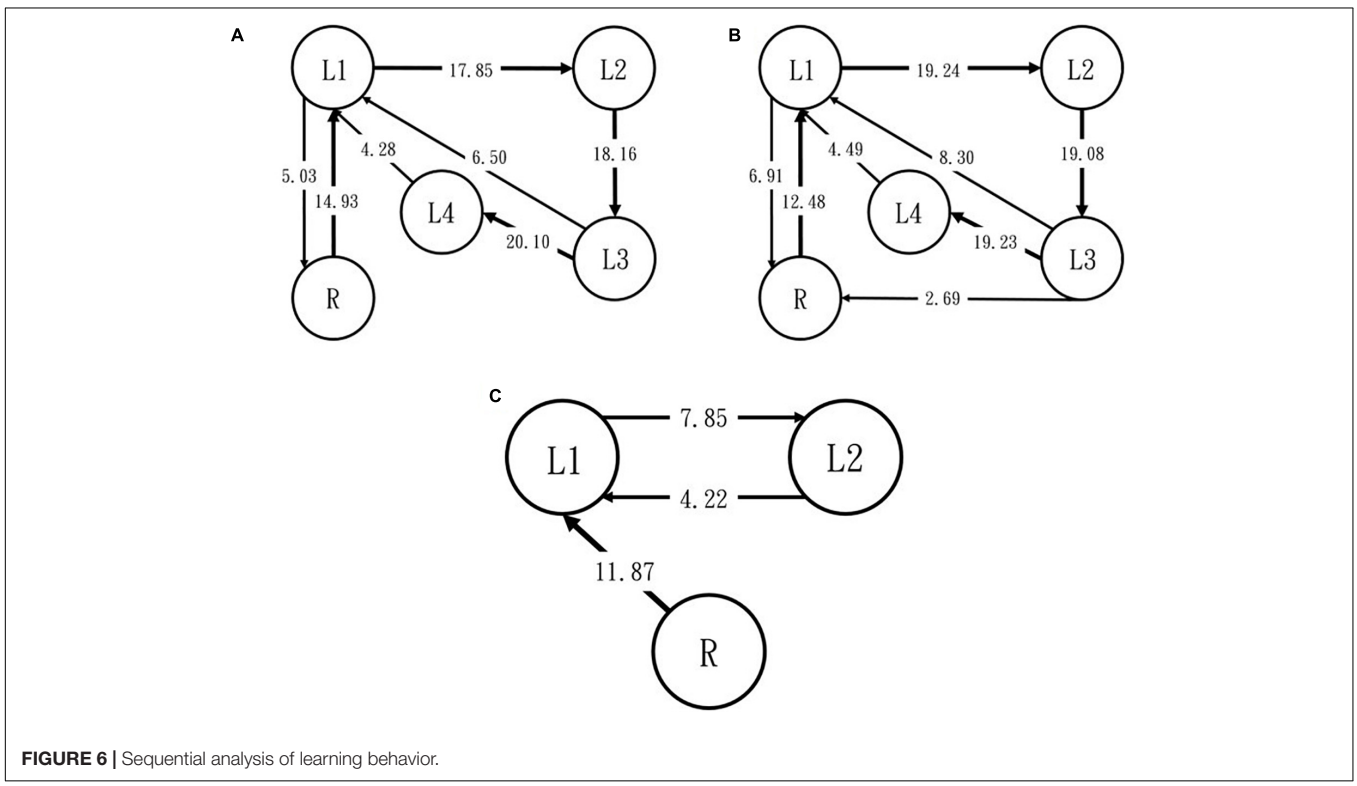

FIGURE 6 | Sequential analysis of learning behavior.

in different groups, a total of six students were invited to conduct individual interviews after the experiment, including three students in the "endogenous two-tier group" and three students in the "exogenous two-tier group."

In the part of the two-tier self-explanation, according to the interview results, learners say that compared with the usual multiple-choice questions, this form of questions can make them rethink the questions and answers. In addition, the way of the second-level questions is very special, which will make people think about the logical concepts carefully. When answering wrong test questions, learners must return for watching relevant parts of the film again. Learners express that they can get immediate feedback, correct their inadequate conceptual understanding immediately, deepen their impression immediately, and make further learning and answer questions more carefully to avoid wrong answers to avoid spending more time watching the film.

In respect to attention cues, according to the results of the central cues representing endogenous (arrow) may be better to keep up with the teacher's teaching progress, know the teacher is now the location of the explanation, and the peripheral cues representing exogenous learners, said although the paragraph text will appear in a sequence, but a lot of time, such as the teacher explained in the same paragraph, the picture is motionless, easily don't know where the teacher is speaking or distracted, but will pay special attention to the red point. The results of this interview were consistent with the results of eye movement analysis. The average gaze duration time and gaze times of the endogenous group were significantly higher than that of the exogenous group. Overall, learners expressed that this kind of learning method is more interesting than the previous static materials, which can increase their interest in learning, and they would like to continue to use this learning method if possible.

DISCUSSION AND CONCLUSION

This study will combine the eye-tracking technology to build a combination of attention cues and a two-tier explanation prompt of the multimedia video learning system, and explore the effect of central cues representing endogenous and peripheral cues representing exogenous on guiding learners' attention and their relationship with learning outcomes. In addition, we explore whether the two-tier self-explanation prompts derived from the two-tier test can improve learners' learning depth and effectiveness, increase knowledge construction in the learning process, and explore the relationship between cognitive load and learning effectiveness. Moreover, this study through the eye-tracker records the eye movement behavior of learners and further analyzes the time series of learner's gaze and regression of location, duration time, frequency, and answering, change the answer, and its influence on learning performance.

(1) **The use of central cues representing endogenous or peripheral cues representing exogenous did not affect learners' learning performances.**

In this study, on behalf of the central cue of endogenous can let learners obtain high attention after learning the post-test, but there was no significant difference. This result can be verified with the research conducted by De Koning et al. (2009, 2010a,b), such that the attention selection and information extraction in learners' perceptual process are not necessarily equal to the understanding in the cognitive process, that is to say, high attention does not necessarily mean better learning outcomes.

(2) **The use of central cues representing endogenous can effectively enhance learners' attention to AOI.**

In this study, the results showed that the average gaze duration time and frequency of the group with endogenous attention cues were significantly higher than those with exogenous attention cues. If the central cue is used as the attention guide in the learning video, compared with the peripheral cue, it can effectively improve learners' attention to the AOI at the right time. Learners in the endogenous groups said arrow made it can easily keep up with the position of the teacher is teaching. And exogenous groups of learners said although the paragraph text will appear in a sequence, a lot of time, such as the teacher explained in the same paragraph, the picture is motionless, and don't know whether the teacher is speaking or distracted, this is consistent with the results of eye movement attention analysis.

(3) **The use of two-tier self-explanation prompts can help improve learners' learning performances.**

Learners adopt two different self-explanation prompts by comparing "endogenous single-tier group" with "endogenous two-tier group." It was found that the learning effect of the endogenous two-tier group was significantly higher than that of the endogenous single-tier group. This indicates that the use of two-tier self-explanation prompts can indeed increase the learner's logical recurrence. Hence, learners can reflect on their answers to first-tier and second-tier questions, help them think and learn deeply to make sure of their answers firmly, and then improve learning effectiveness.

(4) **Learners with two-tier self-explanation prompts had significantly higher learning motivation and reflective than those with single-tier self-explanation prompts.**

This study through the questionnaire to analyze the learners' learning and reflection. By comparing the endogenous single-tier group and the endogenous two-tier group of learners, we found that the learning motivation and reflective of the endogenous two-tier group were significantly higher than that of the endogenous single-tier group. It is indicated that the use of two-tier self-explanation prompts is helpful to enhance learners' learning motivation and reflective.

(5) **The use of two-tier self-explanation prompts can promote learners to rethink the questions of the first tier, modify the answers, and go back to the film for review, which is helpful to improve the learning performance of learners.**

This study through learning behavior patterns analyze whether the single-tier and two-tier self-explanations have any influence on learners' learning behavior. The results of the analysis found that by adopting two-tier self-explanation prompts for learners, when watching the second-tier self-explanation questions and answering the second-tier open-ended questions, students will go back to the first-tier questions and options to reflect on the questions and their answers. The behavior of modifying the answer is added through reflection. After watching the first-tier questions, students will go back to the film for review, and after the review, they will go back to the first-tier questions for reflection again. It is suggested that the use of two-tier self-explanation in learning materials can promote the self-reflection or review behavior of learners, improve their cognitive understanding of knowledge concepts, and improve their learning performances.

But, compared with the two-tier group of learners, learners in the single-tier group were less likely to go back to the film for answers after watching the questions and options. Therefore, the learning achievements of the single-tier self-explaining group are significantly lower than the two-tier self-explaining group.

(6) **There was a significant negative correlation between attention and cognitive load in learners with two-tier self-explanation prompts.**

According to the results of correlation analysis, the attention of learners with two-tier self-explanation prompts is negatively correlated with cognitive load, which means that the higher the attention of learners to the materials, the more cognitive load they can reduce in learning. In addition, the correlation between learning performance and attention did not reach a significant level. This result can be verified with the research conducted by De Koning et al. (2009, 2010a,b) that the attention selection and information extraction in learners' perceptual process are not necessarily equal to the understanding in the cognitive process, that is to say, high attention does not necessarily mean better learning outcomes. Therefore, it is not enough to only guide students' attention in future learning activities, but more importantly, they can participate in the design and guidance of activities. For example, the two-tier question form design in this experiment can help students have a deeper understanding of concepts and internalize knowledge.

To sum up, the research subject of this study is the operating system, which can be applied to other subjects in the future. For the types of multimedia materials, it can also be used to study-related issues, such as whether there is a teacher's head, whether there are subtitles, and the differences between text and animation teaching materials. The types of attention cues can also be extended to other types of attention cues, such as spotlight, gesture, and so on. In the future, they can be used with the brainwave. It can monitor whether learners are focused on the materials and can compare the relationship between the data of the brain wave value and eye movement.

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Y-CK and H-CL conceived and designed the experiments. W-WT performed the experiments. Y-CK and W-WT analyzed the data. H-CL and C-TL contributed reagents, materials, and analysis tools. Y-HL wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

Amadieu, F., Mariné, C., and Laimay, C. (2011). The attention-guiding effect and cognitive load in the comprehension of animations. *Comput. Hum. Behav.* 27, 36–40.doi: 10.1016/j.chb.2010.05.009

Bakeman, R., and Gottman, J. M. (1997). *Observing Interaction. An Introduction to Sequential Analysis*. Cambridge, MA: Cambridge University Press. doi: 10.1017/CBO9780511527685

Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., and Glaser, R. (1989). Self-explanations: how students study and use examples in learning to solve problems. *Cogn. Sci.* 13, 145–182. doi: 10.1207/s15516709cog1302_1

Chi, M. T., Leeuw, N., Chiu, M. H., and LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cogn. Sci.* 18, 439–477. doi: 10.1207/s15516709cog1803_3

Chi, M. T., and Wylie, R. (2014). The ICAP framework: linking cognitive engagement to active learning outcomes. *Educ. Psychol.* 49, 219–243. doi: 10.1080/00461520.2014.965823

Chi, M. T. H. (2000). "Self-explaining expository texts: the dual processes of generating inferences and repairing mental models," in *Advances in Instructional Psychology*, ed. R. Glaser (Mahwah, NJ: Lawrence Erlbaum Associates), 161–238.

Chou, C., Chan, P. S., and Wu, H. C. (2007). Using a two-tier test to assess students' understanding and alternative conceptions of cyber copyright laws. *Br. J. Educ. Technol.* 38, 1072–1084. doi: 10.1111/j.1467-8535.2006.00695.x

Chu, H. C., Hwang, G. J., Tsai, C. C., and Tseng, J. C. (2010). A two-tier test approach to developing location-aware mobile learning systems for natural science courses. *Comput. Educ.* 55, 1618–1627. doi: 10.1016/j.compedu.2010.07.004

De Koning, B. B., Tabbers, H. K., Rikers, R. M., and Paas, F. (2007). Attention cueing as a means to enhance learning from an animation. *Appl. Cogn. Psychol.* 21, 731–746. doi: 10.1002/acp.1346

De Koning, B. B., Tabbers, H. K., Rikers, R. M., and Paas, F. (2009). Towards a framework for attention cueing in instructional animations: guidelines for research and design. *Educ. Psychol. Rev.* 21, 113–140. doi: 10.1007/s10648-009-9098-7

De Koning, B. B., Tabbers, H. K., Rikers, R. M., and Paas, F. (2010a). Learning by generating vs. receiving instructional explanations: two approaches to enhance attention cueing in animations. *Comput. Educ.* 55, 681–691. doi: 10.1016/j.compedu.2010.02.027

De Koning, B. B., Tabbers, H. K., Rikers, R. M., and Paas, F. (2010b). Attention guidance in learning from a complex animation: seeing is understanding? *Learn. Instr.* 20, 111–122. doi: 10.1016/j.learninstruc.2009.02.010

De Koning, B. B., Tabbers, H. K., Rikers, R. M., and Paas, F. (2011). Improved effectiveness of cueing by self-explanations when learning from a complex animation. *Appl. Cogn. Psychol.* 25, 183–194. doi: 10.1002/acp.1661

De Leeuw, N., and Chi, M. T. H. (2003). "The role of self-explanation in conceptual change learning," in *Intentional Conceptual Change*, eds G. Sinatra and P. Pintrich (Mahwah, NJ: Erlbaum), 55–78.

Gibson, B. S. (1996). The masking account of attentional capture: a reply to Yantis and Jonides (1996). *J. Exp. Psychol. Hum. Percept. Perform.* 22, 1514–1520. doi: 10.1037/0096-1523.22.6.1514

Hou, H. T., Sung, Y. T., and Chang, K. E. (2009). Exploring the behavioral patterns of an online knowledge-sharing discussion activity among teachers with problem-solving strategy. *Teach. Teach. Educ.* 25, 101–108. doi: 10.1016/j.tate.2008.07.006

Hwang, G. J., Tung, L. H., and Fang, J. W. (2022). Promoting students' programming logic and problem-solving awareness with precision feedback: a two-tier test-based online programming training approach. *J. Educ. Comput. Res.* 07356331221087773.

Hwang, G. J., Yang, L. H., and Wang, S. Y. (2013). A concept map-embedded educational computer game for improving students' learning performance in natural science courses. *Computers & Education* 69, 121–130. doi: 10.1016/j.compedu.2013.07.008

Jamet, E. (2014). An eye-tracking study of cueing effects in multimedia learning. *Comput. Hum. Behav.* 32, 47–53. doi: 10.1016/j.chb.2013.11.013

Jamet, E., Gavota, M., and Quaireau, C. (2008). Attention guiding in multimedia learning. *Learn. Insrt.* 18, 135–145. doi: 10.1016/j.learninstruc.2007.01.011

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye. *Attent. Perform.* 9, 187–203.

Joseph, J. S., and Optican, L. M. (1996). Involuntary attentional shifts due to orientation differences. *Percept. Psychophys.* 58, 651–665. doi: 10.3758/bf03213098

Kember, D., Leung, D., Jones, A., Loke, A., McKay, J., Harrison, T., et al. (2000). Development of a questionnaire to measure the level of reflective thinking. *Assess. Eval. High. Educ.* 25, 370–380.

Kriz, S., and Hegarty, M. (2007). Top-down and bottom-up influences on learning from animations. *Int. J. Hum. Comput. Stud.* 65, 911–930.

Kwon, K., Kumalasari, C. D., and Howland, J. L. (2011). Self-explanation prompts on problem-solving performance in an interactive learning environment. *J. Interact. Online Learn.* 10, 96–112.

Leijen, Ä, Lam, I., Wildschut, L., Simons, P. R. J., and Admiraal, W. (2009). Streaming video to enhance students' reflection in dance education. *Comput. Educ.* 52, 169–176.

Li, F. Y., Hwang, G. J., Chen, P. Y., and Lin, Y. J. (2021). Effects of a concept mapping-based two-tier test strategy on students' digital game-based learning performances and behavioral patterns. *Comput. Educ.* 173:104293.

Liao, T. H. (2009). *A Pilot Study on the Effects of the Adaptive Pointer on Eye Movement in the Triggered-Based Animated Instructional Design (Master's thesis)*. Taiwan: National Hsinchu University of Education.

Lin, L., and Atkinson, R. K. (2011). Using animations and visual cueing to support learning of scientific concepts and processes. *Comput. Educ.* 56, 650–658.

Lin, L., Atkinson, R. K., Savenye, W. C., and Nelson, B. C. (2016). Effects of visual cues and self-explanation prompts: empirical evidence in a multimedia environment. *Interact. Learn. Environ.* 24, 799–813.

Mayer, R. (2009). *Multimedia Learning*, 2nd Edn. New York: Cambridge University Press.

Odom, A. L., and Barrow, L. H. (1995). Development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction. *J. Res. Sci. Teach.* 32, 45–61.

Ozcelik, E., Arslan-Ari, I., and Cagiltay, K. (2010). Why does signaling enhance multimedia learning? Evidence from eye movements. *Comput. Hum. Behav.* 26, 110–117.

Ozcelik, E., Karakus, T., Kursun, E., and Cagiltay, K. (2009). An eye-tracking study of how color coding affects multimedia learning. *Comput. Educ.* 53, 445–453. doi: 10.1016/j.compedu.2009.03.002

Paas, F. G. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: a cognitive-load approach. *J. Educ. Psychol.* 84, 429–434.

Pintrich, P. R. (1991). *A Manual for the Use of the Motivated Strategies for Learning Questionnaire (MSLQ)*. Ann Arbor, MI: University of Michigan.

Posner, M. I (1980). Orienting of attention. *Q. J. Exp. Psychol.* 32, 3–25. doi: 10.1080/00335558008248231

Posner, M. I., Snyder, C. R., and Davidson, B. J. (1980). Attention and the detection of signals. *J. Exp. Psychol. Gen.* 109:160.

Quinton, S., and Smallbone, T. (2010). Feeding forward: using feedback to promote student reflection and learning–a teaching model. *Innov. Educ. Teach. Int.* 47, 125–135. doi: 10.1080/14703290903525911

Remington, R. W., Johnston, J. C., and Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. *Attent. Percept. Psychophys.* 51, 279–290. doi: 10.3758/bf03212254 .

Theeuwes, J. (1991). Exogenous and endogenous control of attention: the effect of visual onsets and offsets. *Attent. Percept. Psychophys.* 49, 83–90. doi: 10.3758/bf03211619 . doi: 10.3758/BF03211619

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Attent. Percept. Psychophys.* 51, 599–606.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students misconceptions in science. *Int. J. Sci. Educ.* 10, 159–169. doi: 10.1080/0950069880100204

Tsai, C. C. (2003). Using a conflict map as an instructional tool to change student alternative conceptions in simple series electric-circuits. *Int. J. Sci. Educ.* 25, 307–327.

Tsai, C. C., and Chou, C. (2002). Diagnosing students' alternative conceptions in science through a networked two-tier test system. *J. Comput. Assist. Learn.* 18, 157–165. doi: 10.1046/j.0266-4909.2002.00223.x

Tsai, C. C., and She, H. C. (2006). *Use Eye-Tracking System to Investigate Science and Nonscience Elementary School Teachers' Concepts Involving the Animation of Electric Current and their Attention (Master's thesis)*. Taiwan: National Chiao Tung University.

VanLehn, K., Jones, R. M., and Chi, M. T. (1992). A model of the self-explanation effect. *The journal of the learning sciences* 2, 1–59. doi: 10.1207/s15327809jls0201_1

Wang, H. P., and Chen, C. M. (2010). "Assessing the effects of various multimedia curriculums to learning emotion and performance based on emotion recognition technology," in *Proceedings of the 2010 International Symposium on Computer, Communication, Control and Automation* (3CA), Vol. 2 (Tainan: IEEE), 365–368. doi: 10.1109/3CA.2010.5533448

Yang, T. C., Chen, S. Y., and Hwang, G. J. (2015). The influences of a two-tier test strategy on student learning: a lag sequential analysis approach. *Comput. Educ.* 82, 366–377. doi: 10.1016/j.compedu.2014.11.021

Yantis, S., and Jonides, J. (1996). Attentional capture by abrupt onsets: new perceptual objects or visual masking. *J. Exp. Psychol. Hum. Percept. Perform.* 22, 1505–1513. doi: 10.1037//0096-1523.22.6.1505

Yueh, H. P. (2000). A study of classroom management in real-time multicast distance education. *Curr. Instr. Q.* 3, 63–74. doi: 10.1016/S1096-7516(00)00033-6

Zhang, Y. L. (2017). *Examining the Advertising Effect via Eye-tracker Experiments and Surreys:From the Perspective of Cuing Paradigm (Master's thesis)*. Taiwan: Soochow University.

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