MALAYSIAN JOURNAL OF LEARNING AND INSTRUCTION
https://e-journal.uum.edu.my/index.php/mjli

How to cite this article:
Adi Rahmat & Muhamad Wafda Jamil. (2024). Retention-based learning: An approach to maximizing student learning outcomes in high school plant anatomy lesson. *Malaysian Journal of Learning and Instruction, 21*(2), 49-78. https://doi.org/10.32890/mjli2024.21.2.3

RETENTION-BASED LEARNING: AN APPROACH TO MAXIMIZING STUDENT LEARNING OUTCOMES IN HIGH SCHOOL PLANT ANATOMY LESSON

[1]Adi Rahmat & [2]Muhamad Wafda Jamil
Biology Education Study Program,
Universitas Pendidikan Indonesia, Indonesia

[1]Corresponding author: adirahmat@upi.edu

Received: 26/5/2023 Revised: 1/7/2024 Accepted: 22/2/2024 Published: 14/8/2024

ABSTRACT

Purpose – Many students perceive plant anatomy as difficult due to the complexity of the material. Additionally, conventional teaching techniques often neglect the importance of information retention in the learning process. Therefore, this study examines the effects of Retention-Based Learning on students' learning outcomes compared to conventional learning without Retention-Based Learning.

Methodology – A multiple-group time series research design was used to measure the effectiveness of Retention-Based Learning on students' learning outcomes including information retention, cognitive load, and learning achievement. Retention interventions in the Retention-Based Learning class included watching videos, identifying images and answering questions. The participants in this study were seventy-eight 10th-grade public high school students in Bandung, West Java, Indonesia, divided into two research groups.

Findings – This study found that students in the experimental group had better information retention in each lesson and a significantly higher ability to process information with less mental effort and lower cognitive load than the control group. Additionally, the experimental group showed significantly higher learning achievement than the control group. These findings demonstrate the importance of maintaining information retention to maximize learning outcomes in plant anatomy lessons.

Significance – This study indicates that maintaining retention can be a simple and powerful learning approach to help high school teachers teach complex material. The study highlights the significance of maintaining student retention to improve learning performance.

Keywords: Learning approach, cognitive load, plant anatomy, information retention.

INTRODUCTION

Plant anatomy is one of the topics in biology studied by high school students. However, students frequently view plant anatomy as a challenging subject. They perceive it as complex and containing many elements to memorize (Nuraeni et al., 2015). Additionally, the difficulty in learning this material arises from many unfamiliar concepts and terminologies (Sarabi & Gafoor, 2018). Students are often unfamiliar with and have difficulty understanding various plant terms in foreign languages (Wynn et al., 2017). This lack of understanding of the basic concepts makes plant anatomy even more difficult (Zaid & Iksan, 2022). This difficulty is compounded by students' low level of basic understanding. As a result, they find it difficult to connect the structure and function and to interpret images of similar structures (Susiyawati & Treagust, 2021).

Another reason that plant anatomy is considered difficult is that students feel that learning about plants is not very relevant to the environment, especially compared to the study of animals (Bakar et al., 2020). This stems from early perceptions about plants that students bring from childhood (Wynn et al., 2017). Since plants do not move like animals, studying them is perceived as less interesting. Consequently, students may struggle to find real-life examples of plant anatomy, a problem related to the phenomenon of plant blindness (Achurra, 2022). This effect causes students to have limited interest in plants, making learning and retaining the material more difficult. They often face challenges in establishing relevant characteristics of various tissues in different organs. Furthermore, their insufficient knowledge of plant anatomy (Susiyawati & Treagust, 2021) leads to a misunderstanding of the structure and function of plant tissues. From a cognitive perspective, students' inability to remember some parts of plant structures disrupts the cognitive process in their working memory during learning.

Learning difficulties and problems in plant anatomy learning can be viewed through students' cognitive processes. The amount of information students must process is related to the cognitive load of learning this material. Students find it difficult to retain knowledge because of an inadequate working memory (Sweller et al., 2011). Working memory can generally be defined as the processing of information in a limited-capacity storage system, which only handles a limited number of element interactions (Anmarkrud et al., 2019; Kalyuga, 2011; Paas et al., 2003). In learning, working memory capacity describes the capacity of cognitive processes during the learning process (Paas et al., 2003; Sweller et al., 1998). It is important to highlight that working memory is influenced by prior knowledge (Brady et al., 2016; Rahmat et al., 2017; Sobrinho & Souza, 2023). Students will have difficulty processing new information with limited prior knowledge because they lack a familiar context to help them learn. In this case, low prior knowledge of plants, the use of foreign terminology, and students' low interest in learning plant anatomy heavily affect their working memory. Under these conditions, students must exert greater mental effort to process the new information. An increase in students' mental effort indicates that they experience a cognitive load.

Students' considerable mental effort in learning plant anatomy provides the foundation for exploring cognitive load theory. Within this context, exploring cognitive load theory is important to understand the complexities of learning plant anatomy. According to cognitive load theory, total cognitive load consists of three major components in working memory: intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL) (Moreno & Park, 2010; Sweller, 1994). Learning plant anatomy is much more difficult when students cannot find the right balance between these three components. For example, the complexity of vascular tissues in plants, such as xylem and phloem, requires students to grasp various cell types, structures, and physiological processes. Students will likely have a high ICL if the teacher presents the content simultaneously. Additionally, a poorly designed plant anatomy instructional video with distracting visuals, irrelevant background music, and quick transitions between concepts contributes to high ECL (Mayer et al., 2020; Mayer & Moreno, 2003). Thus, working memory becomes full, and GCL space is reduced, leaving students with insufficient capacity to comprehend the lesson. As a result, the failure to comprehend the lesson due to the unbalanced cognitive load will make it difficult for students to promote meaningful processing, affecting their long-term retention of information (van Merriënboer et al., 2006).

Information retention plays an important role in learning plant anatomy, a subject characterized by a significant amount of memorization. Information retention facilitates the activation of prior knowledge, helping students learn subsequent material (Anderson, 2015; Chen et al., 2018; van Kesteren et al., 2018). High information retention enables students to reduce mental effort in learning the material, which indirectly impacts ECL. High retention can be achieved when teachers provide clear information about the structure and function of plant cells and tissues, supported by effective teaching methods. Maintaining information retention impacts students' ability to process new information related to previous material, which reduces their cognitive load and improves their learning achievement. This study examines teachers' strategies to reduce students' cognitive load by promoting Retention-Based Learning (RBL) to maintain information retention during and after the plant anatomy lessons. The objectives of this study are to investigate the effect of Retention-Based Learning on:

1. students' information retention while learning plant anatomy,
2. students' cognitive load during plant anatomy learning,
3. students' learning achievement regarding plant anatomy.

LITERATURE REVIEW

Cognitive Load in Learning

Today's learning design theories emphasize authentic learning tasks based on real-world experiences. These tasks drive learning towards more complex processes, which can place a high load on students' cognitive systems. However, this kind of learning can be effective if the instructional system is designed with consideration of the architecture of the cognitive system (Paas et al., 2003). This can be achieved by incorporating cognitive load theory when developing learning strategies. This theory posits that a person can learn effectively in a given environment if the teacher fully understands the architecture of the student's cognitive system, the learning environment, and the interaction between the two (Kester et al., 2010).

In educational research, cognitive load theory explains the consequences of different types of learning designs (Sweller et al., 2011). It has been used to study the effects of learning strategies on psychological and behavioral changes that describe learning outcomes. Cognitive load describes the degree of difficulty or inability of students to construct knowledge due to poor learning design (Moreno & Park, 2010; Sweller et al., 1998). Cognitive load is a multidimensional construct associated with tasks that stress the cognitive system. It is based on a cognitive architecture consisting of limited working memory to process visual/spatial and auditory/verbal information, which then interacts with unlimited long-term memory (LTM) (Paas et al., 2003). Therefore, cognitive load is related to the ability to make decisions about the information available in working memory. Working memory can be conceptualized as the cognitive resources available to store temporary information for decision-making (Allred et al., 2016).

Total cognitive load comprises three important components in working memory: intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL) (Moreno & Park, 2010; Sweller, 1994). ICL involves the processing of information highly interconnected with working memory to build a cognitive schema. The degree of interconnection between information processing and working memory depends on the complexity of the material being studied (Paas et al., 2003). The number of connections between elements of processed information indicates the level of ICL (Sweller, 1994). Material with a large number of interactive elements is considered more difficult than material with fewer elements or less interactivity (de Jong, 2010). However, ICL depends not only on the characteristics of the material but also on the prior knowledge students bring to the task (Sweller et al., 1998). Thus, ICL results from the interaction of task decisions directly related to the learner's prior knowledge (Chandler & Sweller, 1991). ICL can be managed by adhering to principles such as segmenting (gradual presentation of material), modality (presentation of material in different modalities), and pretraining (helping students acquire prior knowledge) (Mayer & Moreno, 2010).

ECL is a load that occurs separately from the ICL and is primarily the result of poor instructional design (Paas et al., 2003). Overall, ECL is controlled by instructional strategies (Sweller, 1994) but indirectly affect working memory activity related to schema formation in the cognitive system (Kirschner et al., 2009). Unlike ICL, ECL can be controlled through instructional learning design interventions (van Merriënboer & Sweller, 2005). ECL in the learning process can occur due to a "split-attention" situation (divided attention), a redundancy situation (overload information), a transience situation (unfinished information), an advanced learner situation, and can also be caused by inadequate prior knowledge (Mayer & Moreno, 2010).

GCL is also referred to as effective cognitive load, is the mental effort a person makes to form cognitive schemas that help retrieve information presented during the task (Chandler & Sweller, 1991). GCL is influenced by instructional design, which contributes to the construction and automation of knowledge schemas (Paas et al., 2003). The level of GCL learners experience is related to how information is presented and is influenced by the learning activities they perform. Unlike ECL, which is a distraction in the learning process, GCL enhances the learning process (Paas et al., 2003). Several strategies can be used to improve GCL, including providing varied examples (example-based learning), exercises that help students assimilate and adapt, and training students to build concept images through mind maps and concept maps.

To improve learning outcomes, instructional design needs to be planned and delivered in such a way that the cognitive load on the student is reduced. In principle, the entire instructional design will affect the students' cognitive load. Therefore, cognitive load can be used to explain the effects of learning, especially the learning strategies teachers use on the phenomenon of psychological change and behavioral change that describes the achievement of learning outcomes (Moreno & Park, 2010). By analyzing students' cognitive load, teachers can understand how difficult or unable students are in constructing knowledge due to poor learning design (Sweller et al., 1998).

Students' cognitive load during learning can be reduced by controlling elements that affect the three components of cognitive load. GCL heavily depends on ICL, while ICL and ECL determine the total cognitive load. When cognitive load exceeds the capacity of working memory, information processing during learning is disrupted, reducing the use of long-term memory (Sweller, 2010). Therefore, regulating the balance between ICL and GCL is crucial for effective learning (Kester et al., 2010). Additionally, managing ICL and ECL is essential, and in some cases, GCL can also be managed. Experimental studies have shown that students' cognitive load during learning can be reduced by controlling elements that affect ICL, including applying the principles of didactic reduction to the teaching material and providing scientific video shows related to the teaching material to stimulate students' prior knowledge (Rahmat et al., 2017). Furthermore, cues found in multimedia systems are associated with better recall and a reduction in students' overall cognitive load (Xie et al., 2017).

Information Retention

Information processing theory explains how the brain and its memory system operate in processing, storing, and retrieving knowledge from memory (LTM). Memory storage has three important systems: sensory memory, working memory, and LTM (Anderson, 2015). Sensory memory involves the rapid recall of information for about 3-5 seconds for perceptual analysis, which is generally obtained from the senses of sight and hearing (Sternberg & Sternberg, 2011). Working memory is a short-term memory capable of managing information for about 15-20 seconds and can store approximately 5-9 pieces of information due to its limited capacity. Working memory can be used to make decisions because it can be conceptualized as a cognitive resource to store temporary information. It links new information with existing information in LTM, which is organized in the form of cognitive schemata (Schnotz & Kürschner, 2007). LTM is an information storage space with a large capacity that can store information for a long period of time, where knowledge is permanently stored and can be retrieved when needed (Driscoll, 2013).

There are three processes related to memory (Anderson, 2015; Sternberg & Sternberg, 2011). Encoding is the process of transforming new information by integrating it with old information to produce the correct schema. This is done by finding relationships between new information and what is already known. Storage is the process of storing the schema that results from information processing in LTM. Retrieval is the process of retrieving stored information from LTM when needed. Information processing begins with a sensory or perceptual record that enters the register or sensory device. This sensory register receives much information, which is processed directly into working memory to avoid information loss. Two ways to retain information processed in working memory are through practice and rehearsal (Anderson, 2015). Without practice and repetition, information will quickly disappear from memory. Additionally, the loss of information can be caused by new information that is strong enough to dominate existing information. Information that is properly processed in working memory is transferred to LTM for storage.

LTM is closely related to remembering, which is fundamental to human intellectual functioning. Memory is a term used by cognitive psychologists to describe a person's ability to store and use information (Alloway et al., 2009). The memory capacity of each individual is different, so the ability to receive and store information also varies (Foster et al., 2014). All types of learning involve memory, which plays an important role in thinking. This memory refers to the process of retrieving information stored in LTM. The process of retrieving information from LTM is called retention. Retention is related to the durability of information stored in LTM for reuse in a certain time interval (Rose & Strangman, 2007).

Retention is necessary in the learning process because it facilitates the availability of prior knowledge to process new information (Anderson, 2015). This process does not simply reuse what has been stored but uses it in specific situations to solve problems. High retention can be achieved through how teachers deliver clear information, how students are encouraged to be active communicators, how teachers provide opportunities for students to participate in decision-making, and how teachers provide new experiences for students. Teachers can present clear information by displaying visual processes during learning, such as animations (Aslan & John, 2016), learning videos (Brame, 2016; Zhu et al., 2022), pictures (O'Day, 2007; Renkl & Scheiter, 2017), and PowerPoint presentations (Paul & Cicek, 2021). The visualization presented through a medium causes the students to interact, respond, and communicate, making the information that enters memory last longer. For the information to be retained, it must be processed into LTM. This requires mental processes such as focusing attention, evaluating learning outcomes, and emotional factors such as enjoying what is being learned (Kensinger & Corkin, 2003).

For information to remain strongly embedded in memory, maintaining information retention is essential. Strong retention keeps what is known in memory and makes it easier for brain cells to connect when reconstructing new knowledge. When knowledge in LTM is used repeatedly, it can become automated. Knowledge schemes that have become automated can be processed unconsciously, facilitating the reduction of cognitive load (van Merriënboer & Sweller, 2005).

Information retention results from successful learning and determines subsequent learning outcomes. This condition illustrates that each element of information is related, so the retention of information a person has can be used as prior knowledge to process other information. A person will have difficulty processing information if the information components do not have an intrinsic relationship with each other (Anderson, 2015). This indicates a meaningful relationship between retention and cognitive load (Örün & Akbulut, 2019). The stronger the retention of information, the more the cognitive load can be reduced (Xie et al., 2017).

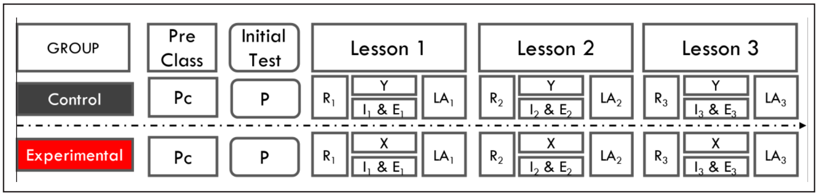
METHODOLOGY

Research Design

This quasi-experimental study was conducted using a multiple-group time series research design (Wiersma, 1995). Details of the research design are shown in Figure 1.

Figure 1

The Research Design to Measure the Effect of RBL on Students' Learning Achievement in Learning Plant Anatomy



Pc: Preclass session before the actual learning; P: Initial test for prior knowledge (pretest); R_1, R_2, R_3: Test for information retention; I_1, I_2, I_3: Intrinsic cognitive load data collection; E_1, E_2, E_3: Extraneous cognitive load data collection; LA_1, LA_2, LA_3: Test for learning achievement; X: Learning by maintaining information retention (Retention-Based Learning/RBL); Y: Learning without maintaining information retention.

Participants

The biology teacher and all students gave their informed consent to participate in this study. The participants in this study were seventy-eight 10th-grade science students from a public high school in Bandung, West Java, Indonesia. All participants were between the ages of 15–16 and were divided into two classes with similar academic achievements. The experimental group consisted of 14 male and 25 female students, while the control group consisted of 16 male and 23 female students. The class was taught by a native biology teacher.

Research Procedure

The plant anatomy lessons for both the control and experimental groups were divided into three sessions. One week before the first lesson, students in both groups attended a pre-lesson to stimulate their knowledge of plant anatomy (Pc). The pre-lesson is not regarded as a compulsory undertaking for students, thereby guaranteeing their active involvement without any form of compulsion from the teacher. The first session (lesson 1) covered tissue systems in plants, the second session (lesson 2) covered the role and position of tissues in plant organs, and the third session (lesson 3) covered the modification of tissue structures in plant organs. The content of lessons 1 to 3 was developed, with increasing complexity.

Students' information retention in both groups was measured at the beginning of each lesson (R1, R2, R3). Learning in the experimental group was conducted using RBL, which consists of four learning stages: (1) apperception, (2) concept exploration, (3) presentation and discussion of the concepts, (4) confirmation, reinforcement, and retention of the concept. The learning stages for each lesson is described in Table 1. Information retention in the experimental group was refreshed by reactivating relevant information through videos, images, and questions in phases 1-3 (Table 1). These interventions were repeated in each lesson, increasing the number of retention test items (R1, R2, R3) as the lessons progressed.

In the control group, learning was carried out using the practical method, which involved observing preserved plant tissue preparations guided by worksheets (Y). Information Processing (I), which describes the extent of the students' ICL, and Mental Effort (E), which describes the students' ECL, were measured during the lesson. Learning Achievement (LA), which describes students' GCL, was measured at the end of each lesson.

Table 1

Retention-Based Learning Strategy in a Plant Anatomy Lesson

Phase	Learning Activity
Apperception (stimulation of prior knowledge and learning orientation).	• Stimulate prior knowledge (the structure of plant cells) by showing animated videos and images of plant cells, followed by questions. • Connect previous material with material to be discussed. • Deliver learning objectives.
Concept Exploration (gathering new concepts, retaining previous information, and rehearsing new concepts).	• Observe and identify the concept of plant tissue presented through animated videos, images, and plant tissue preservation preparations observed with a light microscope (gathering new information). • Discuss results of observations and identification of plant tissues. • Guide discussion by asking questions and showing animated videos or images to help students recall previous concepts so that students can easily assimilate and accommodate the new concept.
Presentation and discussion of concept.	• Present and discuss the structure of plant tissues and their relationship with the function of plant organs obtained in the Concept Exploration phase.
Confirmation, reinforcement, and retention of new concept.	• Ask questions confirming the information learned in the previous phase (phase 2 and 3). • Reinforce key points by showing videos or images of plant tissue structures and their relationship with plant organ function.

The video used in this study is an animated video explaining plant tissue types and systems. The video shows the structure of plant tissues in two and three dimensions. Additionally, in the middle of the video session, the teacher provides cues to emphasize some basic relevant concepts that students need to understand before moving on to another concept. The selection of videos in this study refers to Brame's (2016) weeding technique, which ensures that videos do not contain background music and complex background images to avoid becoming an extraneous cognitive load during learning. Images used in the study were photos of observations of fresh and preserved slides, and diagrams of plant structures. Questions were given to students in phases 1, 2 and 4 to guide and remind them of the concepts that have been and are being taught. These questions were presented orally and in multiple-choice form. Multiple-choice questions provided cues for students to recall the concepts they had learned.

Instrument

Retention Test (R). The retention test format consisted of five multiple-choice questions. The first retention test had 5 questions. These initial five questions were included again in the second retention test, with five new questions added based on the material studied. This pattern continued until the third retention test, resulting in 15 questions for the third retention test. The retention test instruments for lessons 1, 2, and 3 demonstrated moderate reliability (Cronbach's α = .75, .76, and .78). The questions used to measure retention were developed based on level 1 of the cognitive process in the New Taxonomy of Educational Objectives by Marzano and Kendall (2007) which involves recalling and recognizing. For recall, students were asked to name the type and anatomical structure of plants. In the recognizing phase, students were asked to validate the correct statement related to the name, type and anatomical structure of plants (Marzano & Kendall, 2008).

Cognitive Load. The cognitive load measured in this study includes intrinsic and extraneous cognitive load. All instruments to measure cognitive load were developed according to the criteria described by Brünken et al. (2010). Students' intrinsic cognitive load (I) was measured by their ability to process information from the teacher or the instructional task design. The intrinsic cognitive load instrument had moderate reliability, with Cronbach's α = .71. The information processing ability was assessed using a task complexity worksheet given to the students alongside the teaching process. The worksheet was developed based on information processing standards, including information components, interpretation, relevance, and application (Marzano et al., 1993). Extraneous cognitive load (E) was measured by collecting students' mental effort using a reversed scale questionnaire with ratings ranging from 1 (helpful) to 7 (very unhelpful).

Learning Achievement (LA). In this study, student learning achievement indicates the magnitude of the student's GCL. The instrument used for measuring student learning consisted of multiple-choice questions and contained 20 items. The learning achievement instrument had moderate reliability, with Cronbach's α = .78. The instruments were developed based on Marzano and Kendal's Taxonomy of Educational Learning Objectives (2007) at level 2 (comprehension), which includes integrating and symbolizing, and level 3 (analysis), which includes matching, classifying, generalizing, and specifying.

Data Analysis

The differences in retention, ICL, ECL, and LA between the control and experimental group students in each lesson were analyzed using an independent t-test. ANOVA was used to test for differences in information retention among the three lessons in the control and experimental groups. The level of cognitive load was described based on the correlation between intrinsic cognitive load and extraneous cognitive load (Sweller et al., 2011). In this study, cognitive load was assumed to be low when information processing and mental effort were negatively correlated.

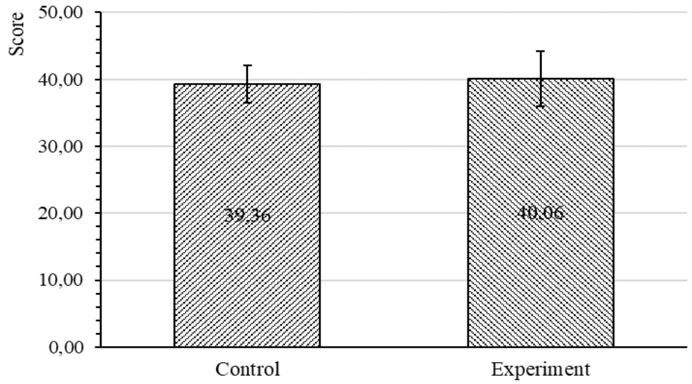
RESULTS AND DISCUSSION

Students' Prior Knowledge

The initial test (pretest) was conducted to measure students' prior knowledge of plant anatomy. The average score of the control group (M = 39.36, SD =16.74) compared to the experimental group (M = 40.76, SD = 24.79) showed no significant differences (p = .893). This result illustrates that the control and experimental groups had the same prior knowledge of plant anatomy (Figure 2). Although the students had previously learned about the introduction to plant anatomy in junior high school, the previous course only covered a small portion of the materials. Furthermore, the course was taught two to three years ago, and students possibly forgot many topics.

Figure 2

The Pretest Score (Prior Knowledge) of the Control and Experimental Groups. The Error Bars Show Standard Errors



The Effects of Retention-Based Learning on Students' Information Retention

The teaching material for lesson 1 focused on the structure of plant tissues, including meristems, dermal tissue systems, and vascular tissue systems. Several videos about various types of plant tissues were shown to the students before the learning session began. In both the control and experimental groups, retention tests were conducted during the first meeting on plant cell structure material, which forms the basis for understanding plant tissue structures. The statistical test results showed no significant difference in information retention (p = .510) between the control and experimental groups in lesson 1. The average retention test score of the control group was M = 64.03 (SD = 10.37), while the experimental group scored M = 65.50 (SD = 12.40) (Figure 3). These data indicated that the intervention in the first week did not have a significant impact on the students in the experimental group, likely due to their lack of basic knowledge about plant tissue structures.

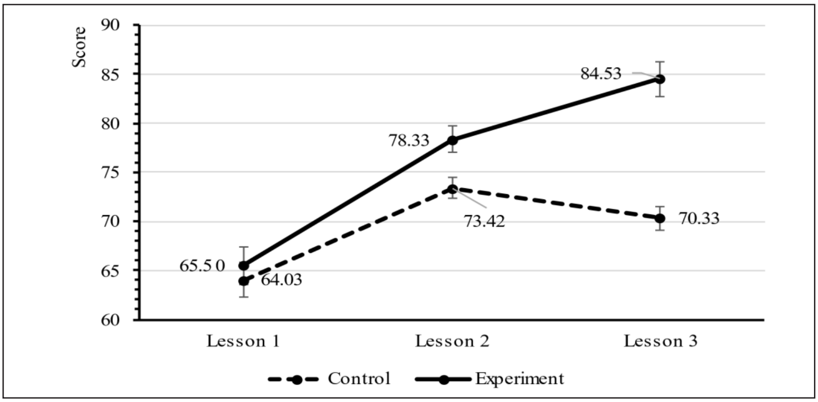
A week later, the retention test for the material on plant cells and tissue structure was conducted in the second meeting (lesson 2). Both materials are essential for students to understand the structure of plant organs. The retention test results for the control and experimental groups showed a significant increase from the first test. However, there was also a significant difference (p = .035) with the experimental group scoring higher (*M* = 78.33, *SD* = 8.04) than the control group (*M* = 73.42, *SD* = 6.61). This suggests that the students in the experimental group, who were taught using RBL, tended to remember more material from the previous meeting, indicating that RBL is beginning to benefit them.

The student retention test in lesson 3 covered plant cell structure, plant tissue structure, and plant organ structure. These materials are essential for understanding and identifying plant tissues in various plant organs with modified anatomical structures. As the material became more complex, the retention test results in lesson 3 between the control and the experimental groups showed a significant difference ($p < .001$). The intervention continued to show beneficial effects on maintaining students' retention, as evidenced by the experimental group's retention test results in lesson 3 (*M* = 84.53, *SD* = 10.76), which were higher than their results in lesson 2 (Figure 3). This emphasizes that RBL helps the students remember more material than conventional learning methods.

In contrast, the retention of students in the control group was lower than in the previous retention test due to the lack of strategies for maintaining retention. As the learning material became more complex, students' learning without intervention showed a clear indication of forgetting. Most of the material that they could not remember was from the first week's content, indicating that their retention weakened over time.

Figure 3

The Average Score of the Information Retention Test for Each Lesson. The Error Bars Show Standard Errors



The students who received the intervention including videos, images, and questions, demonstrated better retention compared to the control group. The interventions engaged students actively in classroom learning, facilitating more frequent retrieval of information and reducing the likelihood of forgetting the lessons (Anderson, 2015). In contrast, the retention test results in lesson 3 for the control group (M = 70.33, SD = 7.14) were lower than those in lesson 2, indicating a decline in information retention among control group students. The progressive increase in information retention scores from lesson to lesson highlights the effectiveness of RBL in helping students maintain their retention levels.

Visual aids, particularly images, play a crucial role in facilitating students' comprehension of complex topics like plant anatomy. These subjects require appropriate visual representations of plant parts to aid learning effectively. By providing images depicting plant structures, students gain a clearer and more concise visual understanding of the organization and details of these plant parts. Visual aids are inherently easier to remember than text. Furthermore, in the context of a paper-based test, the inclusion of images serves as potent memory cues that stimulate the retrieval of plant structures on test day. Additionally, the static images enable students to visualize the intricate components of plant tissue structures, providing a basic understanding crucial for LTM consolidation.

With the understanding of plant tissue structures from the images, the videos helped the students have better spatial visualization as plant anatomy requires students to visualize models in three dimensions. The videos also provide a dynamic representation of plant anatomy, showing the structure and process inside plants because students need to understand the interrelation between structure and functions. Students can understand many key aspects of plant structure and function, including growth and development, physiological processes, and interactions between plant parts. The video-audio narration also helped the students understand the concept of plant tissues. As a result, watching plant anatomy videos in class directs students to use visual and auditory channels to understand the information shown, which can increase student retention (Mayer & Moreno, 2003). As the videos were given before and during the learning, the students remembered the material from previous and upcoming learning, which helped them maintain their retention.

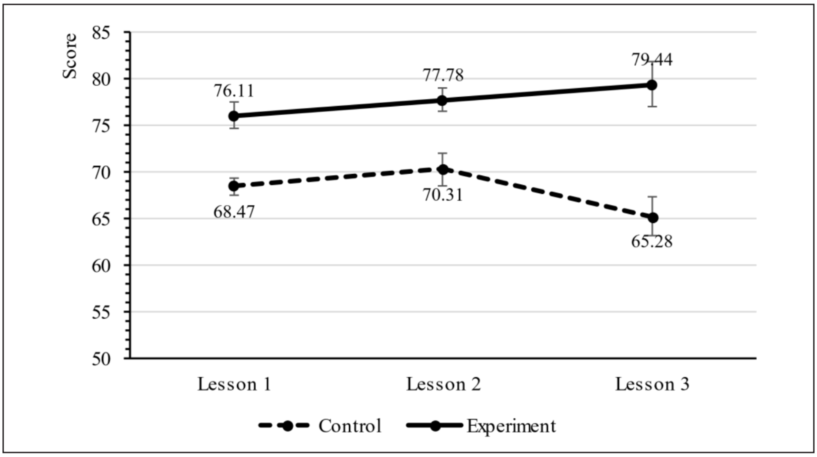
Additionally, providing students with the opportunity to answer several plant anatomy questions during class made the learning in the experimental group more student-centered compared to the control group. Answering questions requires students to retrieve and apply their knowledge, which can strengthen their memory. Thinking about answers helped activate cognitive processing, facilitating better consolidation of the material in LTM. Furthermore, students received direct feedback while answering the questions, regardless of the quality of their responses. In addition to correcting students' answers, the teacher encouraged other students to provide their opinions on their classmates' responses. This aspect of the intervention proved beneficial not only for the students who answered but also for those who engaged in discussing their peers' answers. This finding aligns with studies by Nayak et al. (2017) which indicated that answering teachers' questions contributed to students' retention and recollection of information during class. The student who answered questions in the experimental group found the experience challenging but acknowledged its positive impact on their learning performance.

The Effects of Retention-Based Learning on Students' Cognitive Load

Intrinsic cognitive load describes students' ability to process information or knowledge presented by the teacher during learning. The statistical analysis showed that students' information processing ability in the experimental group was significantly higher than that of students in the control group in lesson 1 ($p < .001$), lesson 2 ($p = .003$), and lesson 3 ($p < .001$). Meanwhile, there was no significant difference in information processing lessons 1, 2, and 3, both in the experimental group ($p = .400$) and the control group ($p = .101$). However, the information processing score in the experimental group tended to increase from lesson 1 to lesson 3. In contrast, in the control group, the increase in information processing only occurred in lesson 2, followed by a decrease in lesson 3 (Figure 4).

Figure 4

Students' Ability in Information Processing in Three Lessons of Plant Anatomy. The Error Bars Show Standard Errors



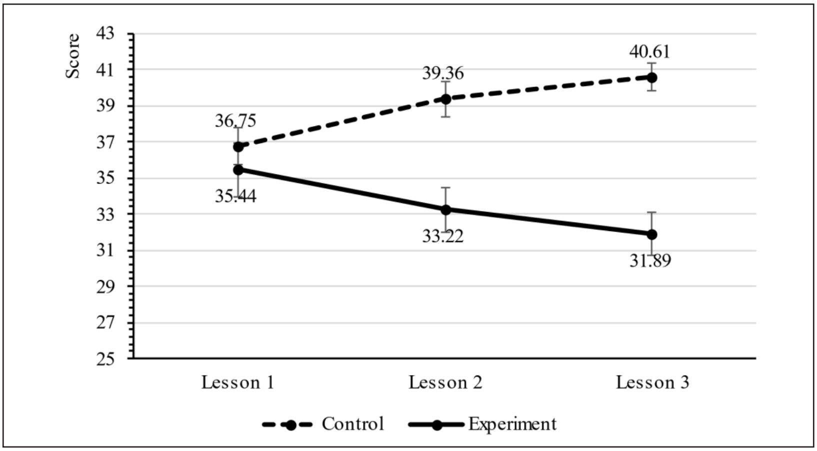
The statistical analysis of information processing indicates that the intervention to maintain students' prior knowledge supported their ability to process the information provided by the teacher. The results showed that the intrinsic cognitive load of the students in the experimental group was higher compared to the control group and tended to increase from lesson 1 to lesson 3. This was because students in the experimental group had more information to process than those in the control group. On the other hand, aligned with Faulconer et al. (2022), the discussion session in the middle of learning introduced greater intrinsic and extraneous cognitive load. Although the intrinsic cognitive load was higher in the three lessons, the students did not feel exhausted because the videos and images given during the lessons were relevant to the current and previous learning material. The intervention effectively managed their cognitive load and prevented cognitive overload by ensuring that the students were processing the right information. These findings were also consistent with the student retention data in Figure 3. The data showed that students with sufficient ability to process information in each session could better recall their prior knowledge, thus impacting learning performance (van Riesen et al., 2022). This suggests that the intervention successfully facilitated students in promoting elaboration between prior knowledge and new information, as the features of plant anatomy are interrelated.

Students' extraneous cognitive load was described by their mental effort during the learning process. In the first session (lesson 1), neither the control nor the experimental group showed significant differences ($p = .473$) because the complexity of the material was low. However, the two classes showed significant differences in mental effort in lesson 2 ($p < .001$) and lesson 3 ($p < .001$). Although the intrinsic cognitive load of the students in the control group was lower than in the experimental group, they found that learning without maintaining retention required more effort because they had difficulty retrieving the previous material. Without proper prior knowledge, they needed to put greater mental effort into learning the material as the lessons became more complex. Conversely, due to the intervention, the students in the experimental group found that their efforts to maintain retention before and during class made the lessons much easier.

The difference in the mental effort between the control and experimental groups became apparent when the mental effort of the students in the control group increased in lesson 3. Although the mental effort of the students in the control group in lesson 3 was not significantly different from their mental effort in lesson 2 ($p = .218$), the statistical test results showed a significant difference compared to their mental effort in lesson 1 ($p = .018$). On the other hand, the mental effort of the students in the experimental group decreased by lesson 3, although there was no significant difference (Figure 5). This shows that students in the control group had difficulty processing the information as the complexity of the material increased.

Figure 5

Students' Mental Effort in Learning Plant Anatomy. The Error Bars Show Standard Errors



The intervention in the experimental group effectively reduced students' mental effort in several ways. Providing students with videos before and during the plant anatomy lesson helped them to have lower mental effort. It emphasizes that giving students supplemental material, such as videos in addition to textbooks, could enhance their learning engagement and motivation (Stockwell et al., 2015). In this case, the images and videos serve as visual aids that lower cognitive demand by providing more resources for information processing. The images and videos helped students build connections between concepts and reduced the cognitive effort to remember the materials. According to Mayer's theory of multimedia learning, images combined with videos increase the quality of the learning process. Furthermore, the narration in the video provides visual and auditory cues. This dual sensory input helped students to process the information more efficiently (Brame, 2016).

Additionally, students' active learning in the experimental group by answering questions made the learning more engaging. Answering questions during class acted like retrieval practice (Agarwal et al., 2020), which can reduce memory load and make the plant anatomy lesson easier to recall during each lesson. Thus, the students in the experimental group were not overwhelmed by each lesson because they were already familiar with answering questions during class. The student's information retention from previous lessons significantly reduced the gap between prior knowledge and new information. Conversely, the mental effort level of students in the control group showed a huge gap between prior knowledge and incoming materials due to the content they had forgotten, as the retention rate decreased in lesson 3. Apart from that, the feedback from the teacher and other students provided a better constructive understanding of the materials, which reduced mental effort by clarifying misconceptions during learning. The students who corrected other students' answers also benefitted because they could assess their understanding in comparison to others. Clarifying answers supports the integration of their current understanding with new information (Lavy & Shriki, 2022), which motivates students to put their best effort into learning (Maslova et al., 2022).

Students' cognitive load was analyzed by measuring the correlation between intrinsic and extraneous cognitive load. Students in the control group showed a positive correlation in lesson 1 and lesson 3 but a negative correlation in lesson 2. On the other hand, there is a negative correlation between information processing and mental effort in the experimental group across all lessons (Table 2).

Table 2

The Correlation Coefficient between Students' Information Processing and Mental Effort

Control Group			
Var	Lesson 1 **ME**	Lesson 2 **ME**	Lesson 3 **ME**
IP	.09	-.14	.05
Experimental Group			
Var	Lesson 1 **ME**	Lesson 2 **ME**	Lesson 3 **ME**
IP	-.15	-.40*	-.58**

* $p < .05$

** $p < .01$

Note: Var = Variable; IP = Information Processing; ME = Mental Effort

This data shows that managing students' information retention significantly affects students' cognitive load. Students in experimental groups with better information retention have a lower cognitive load because their working memory has more free space to store information efficiently. Additionally, these students have better memory retention, allowing them to elaborate on previous information with new information in each lesson. This is compared to the control group, which had high cognitive load levels because they had to put extra effort into recalling previous knowledge and combining it with current learning materials.

Maintaining retention through providing videos is believed to enhance germane cognitive load by helping students recognize what lesson will be learned next (Brame, 2016). With the high complexity of the plant anatomy course, the videos helped students construct their comprehension of the topic rather than relying solely on textbooks. On the other hand, students' working memory in the control group may be overloaded because they did not have any preparation, making learning less effective (Azman & Johari, 2022). Students' cognitive load in the experimental group tends to be lower than in the control group because the videos helped demonstrate the complex plant anatomy concepts, making them easier and more engaging for students. Another explanation is that the videos provide multimedia effects due to combinations of visual and auditory learning resources that alter student cognitive load during the learning process (Schüler et al., 2013). Furthermore, pausing the videos to emphasize some content served as a cue, which helped students reduce their unnecessary cognitive load (Tannert et al., 2023).

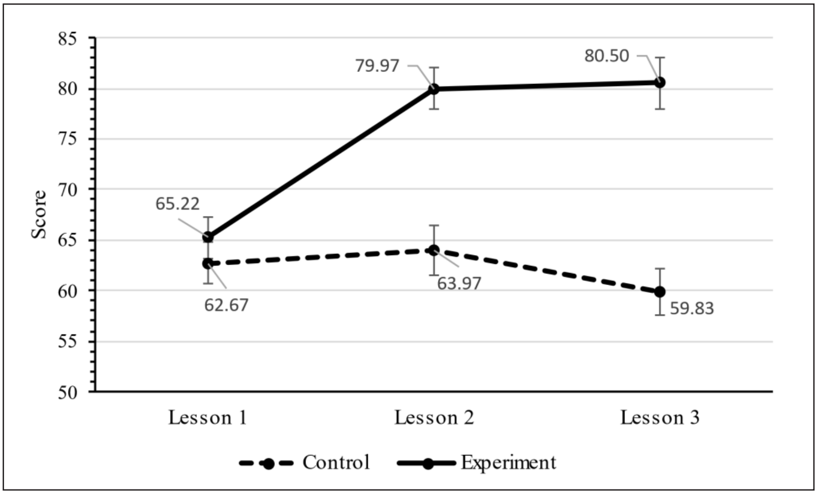
In addition, students in the experimental group who were prompted to answer questions during class demonstrated superior attention spans in comparison to those in the control group. This behavior of paying attention is believed to reduce cognitive load by allowing students to understand the questions and give proper answers. Answering questions during class is a form of retrieval practice (Agarwal et al., 2020) that helps students to recall information in each lesson. Furthermore, when students tried to answer questions, it forced them to think more about the plant anatomy material in each lesson and elaborate on their understanding.

The Effects of Retention-Based Learning on Students' Learning Achievement

The effectiveness of maintaining information retention was measured by how well the output of the learning process is. The data shows that students in the experimental group have better learning achievement in plant anatomy lessons (Figure 6).

Figure 6

Students' Learning Achievements in Plant Anatomy. The Error Bars Show Standard Errors



There is no significant difference in lesson 1 between the control and experimental groups (p = .062). However, as the learning process progresses, the experimental group significantly surpasses the control group. The experimental group outperformed the control group very significantly in lesson 2 ($p < .001$) and lesson 3 ($p < .001$). The trend of this chart is also similar to students' retention performance (Figure 3), where the significant impact of the intervention was visible in lessons 2 and 3, emphasizing that students with better retention have better learning achievements. Maintaining retention supports transferring knowledge and applying new materials to higher level thinking questions. The ability to apply knowledge has the highest contribution because most questions measuring learning achievement involve memorization and applying knowledge skills. In contrast, students in the control group have lower learning achievement due to the increasing mental effort during each session, which causes a reduction in their working memory resources, resulting in decreased learning achievement (Chen et al., 2018).

The intervention, especially videos during class, may influence exam grades (Zhu et al., 2022). Consistent results have also reported that providing videos during biology learning results in better student learning achievement in flipped learning environments, even if the videos are served before class (Azman & Johari, 2022). Providing images and videos during plant anatomy learning helped students understand the parts of the plants being explained by the teachers, reducing the potential of mislabeling various plant parts and their functions. This is important to consider because an undetected misconception about plant parts in a previous lesson could have a significantly negative impact on students' understanding, thus ruining their learning achievement. Answering questions gives students a better chance to explain their understanding, which helps them build a solid elaboration between concepts in plant anatomy. It assists students in thinking conceptually because the intervention also helps students engage in each learning session (Rich et al., 2014).

CONCLUSION

The study found that the implementation of RBL, through the effective presentation of videos, images, and questions, contributed to a better understanding of the topic of plant anatomy for high school students. The findings suggest that RBL can help students retain knowledge, process information more easily, and reduce cognitive load during learning. Students are most likely to benefit from their lessons when they can effectively retain information and experience reduced cognitive load. To promote better learning achievement and create a student-centered learning environment, teachers should emphasize memory retention during class. Implementing RBL when teaching plant anatomy at the high school level can lead to a better learning experience and more effective learning.

The use of English language in students' textbooks for images and videos may reduce students' ability to learn plant anatomy. Although the students did not raise any objections to the English language videos, it is important to consider that not all students in the experimental group have a sufficient level of English language proficiency. Future studies should ensure that the materials are presented in the students' native language. The research findings suggest that retention-based learning techniques have the potential to improve high school education by providing an optimal learning environment for students to reach their full potential in plant anatomy. However, further research is needed to determine the long-term effects of retention-based learning and to evaluate its benefits over time. A deeper understanding of the lasting effects of this learning approach will enable teachers to modify and improve the teaching of plant anatomy, or even other high school subjects.

ACKNOWLEDGMENT

This research received no specific grant from any funding agency in the public, commercial, or not-for profit sectors and has been approved by the Ethical Reviewer of the Faculty of Mathematics and Natural Sciences Education, number 7102/UN40.F4/PT.01.03/2023

REFERENCES

Achurra, A. (2022). Plant blindness: A focus on its biological basis. *Frontiers in Education*, *7*, 963448. https://doi.org/10.3389/feduc.2022.963448

Agarwal, P. K., Roediger, H. L., McDaniel, M. A., & McDermott, K. B. (2020). *How to use retrieval practice to improve learning*. http://pdf.retrievalpractice.org/RetrievalPracticeGuide.pdf

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The cognitive and behavioral characteristics of children with low working memory. *Child Development*, *80*(2), 606–621. https://doi.org/10.1111/j.1467-8624.2009.01282.x

Allred, S. R., Crawford, L. E., Duffy, S., & Smith, J. (2016). Working memory and spatial judgments: Cognitive load increases the central tendency bias. *Psychonomic Bulletin & Review*, *23*(6), 1825–1831. https://doi.org/10.3758/s13423-016-1039-0

Anderson, J. R. (2015). *Cognitive psychology and its implications* (8th ed.). Worth Publishers.

Anmarkrud, Ø., Andresen, A., & Bråten, I. (2019). Cognitive load and working memory in multimedia learning: Conceptual and measurement issues. *Educational Psychologist*, *54*(2), 61–83. https://doi.org/10.1080/00461520.2018.1554484

Aslan, A., & John, T. (2016). The development of adaptive memory: Young children show enhanced retention of animacy-related information. *Journal of Experimental Child Psychology*, *152*, 343–350. https://doi.org/10.1016/j.jecp.2016.07.007

Azman, A. N., & Johari, M. (2022). Investigating the effectiveness of videos designed using cognitive load theory on biology students' academic achievement. *Jurnal Pendidikan IPA Indonesia*, *11*(3), 461–468. https://doi.org/10.15294/jpii.v11i3.37324

Bakar, F., Avan, Ç., Şeker, F., & Aydinli, B. (2020). Plant and animal awareness in nature education perspectives: Where is blindness? *International Electronic Journal of Environmental Education*, *10*(2), 122–136.

Brady, T. F., Störmer, V. S., & Alvarez, G. A. (2016). Working memory is not fixed-capacity: More active storage capacity for real-world objects than for simple stimuli. *Proceedings of the National Academy of Sciences*, *113*(27), 7459–7464. https://doi.org/10.1073/pnas.1520027113

Brame, C. J. (2016). Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE—Life Sciences Education*, *15*(4), es6. https://doi.org/10.1187/cbe.16-03-0125

Brünken, R., Plass, J. L., & Moreno, R. (2010). Current issues and open questions in cognitive load research. In *Cognitive Load Theory*. Cambridge University Press.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293–332. https://doi.org/10.1207/s1532690xci0804_2

Chen, H., Ning, X., Wang, L., & Yang, J. (2018). Acquiring new factual information: Effect of prior knowledge. *Frontiers in Psychology*, *9*.

Chen, O., Castro-Alonso, J. C., Paas, F., & Sweller, J. (2018). Extending cognitive load theory to incorporate working memory resource depletion: Evidence from the spacing effect. *Educational Psychology Review*, *30*(2), 483–501. https://doi.org/10.1007/s10648-017-9426-2

de Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. *Instructional Science*, *38*(2), 105–134. https://doi.org/10.1007/s11251-009-9110-0

Driscoll, M. P. (2013). *Psychology of learning for instruction* (3rd ed.). Pearson Education.

Faulconer, E. K., Bolch, C., & Wood, B. (2022). Cognitive load in asynchronous discussions of an online undergraduate STEM course. *Journal of Research in Innovative Teaching & Learning*. https://doi.org/10.1108/JRIT-02-2022-0010

Foster, J. L., Shipstead, Z., Harrison, T. L., Hicks, K. L., Redick, T. S., & Engle, R. W. (2014). Shortened complex span tasks can reliably measure working memory capacity. *Memory & Cognition*, *43*(2), 226–236. https://doi.org/10.3758/s13421-014-0461-7

Kalyuga, S. (2011). Informing: A cognitive load perspective. *Informing Science: The International Journal of an Emerging Transdiscipline*, *14*, 033–045. https://doi.org/10.28945/1349

Kensinger, E. A., & Corkin, S. (2003). Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words? *Memory & Cognition*, *31*(8), 1169–1180. https://doi.org/10.3758/BF03195800

Kester, L., Paas, F., & van Merriënboer, J. J. G. (2010). Instructional control of cognitive load in the design of complex learning environments. In J. L. Plass, R. Moreno, & R. Brünken, *Cognitive Load Theory*. Cambridge University Press.

Kirschner, F., Paas, F., & Kirschner, P. A. (2009). A cognitive load approach to collaborative learning: United brains for complex tasks. *Educational Psychology Review*, *21*(1), 31–42. https://doi.org/10.1007/s10648-008-9095-2

Lavy, I., & Shriki, A. (2022). Cognitive load and question asking – The case of prospective mathematics teachers coping with historical texts. *Education and New Developments 2022, I*, 427–431. https://doi.org/10.36315/2022v1end097

Marzano, R. J., & Kendall, J. S. (2007). *The new taxonomy of educational objectives* (Second). Corwin Press.

Marzano, R. J., & Kendall, J. S. (2008). *Designing & assessing educational objectives: Applying the new taxonomy*. Corwin Press.

Marzano, R. J., Pickering, D. J., & McTighe, J. (1993). *Assessing student outcomes: Performance assessment using the dimensions of learning model*. Association for Supervision and Curriculum Development.

Maslova, A., Koval, O., Kotliarova, V., Tkach, M., & Nadolska, Y. (2022). On the way to successful learning and teaching: Constructive feedback. *Journal of Higher Education Theory and Practice*, *22*(6). https://doi.org/10.33423/jhetp.v22i6.5233

Mayer, R. E., Fiorella, L., & Stull, A. (2020). Five ways to increase the effectiveness of instructional video. *Educational Technology Research and Development*, *68*(3), 837–852. https://doi.org/10.1007/s11423-020-09749-6

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*(1), 43–52. https://doi.org/10.1207/S15326985EP3801_6

Mayer, R. E., & Moreno, R. (2010). Techniques that reduce extraneous cognitive load and manage intrinsic cognitive load during multimedia learning. In J. L. Plass, R. Moreno, & R. Brünken (Eds.), *Cognitive Load Theory* (pp. 131–152). Cambridge University Press.

Moreno, R., & Park, B. (2010). Historical development and relation to other theories. In J. L. Plass, R. Brünken, & R. Moreno, *Cognitive Load Theory*. Cambridge University Press.

Nayak, S., Rao, M., Sundarshan, S., Naveen, K., Rao, S., & Aithal, A. (2017). “Question of the day”: Impact on learning and retention. *Kathmandu University Medical Journal*, *13*(3), 204–211. https://doi.org/10.3126/kumj.v13i3.16801

Nuraeni, E., Redjeki, S., & Rahmat, A. (2015). Perkembangan literasi kuantitatif mahasiswa biologi dalam perkuliahan anatomi tumbuhan berbasis dimensi belajar. *Jurnal Ilmu Pendidikan*, *21*(2), 127–135. https://doi.org/10.17977/jip.v21i2.5836

O’Day, D. H. (2007). *The value of animations in biology teaching: A study of long-term memory retention*. *6*.

Örün, Ö., & Akbulut, Y. (2019). Effect of multitasking, physical environment and electroencephalography use on cognitive load and retention. *Computers in Human Behavior*.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1–4. https://doi.org/10.1207/S15326985EP3801_1

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*(1), 63–71. https://doi.org/10.1207/S15326985EP3801_8

Paul, J. W., & Cicek, J. S. (2021). The cognitive science of powerpoint part II: The power of attention. *Proceedings of Canadian Engineering Education Association*, 19–22. https://doi.org/10.24908/pceea.vi.15834

Rahmat, A., Soesilawaty, S. A., Nuraeni, E., & Hidayat, T. (2017). Controlling cognitive load of high school student in biology class control de la carga cognitiva de estudiantes de bachillerato en la clase de biología. *Journal of Science Education*, *18*(2), 105–108.

Renkl, A., & Scheiter, K. (2017). Studying visual displays: How to instructionally support learning. *Educational Psychology Review*, *29*(3), 599–621. https://doi.org/10.1007/s10648-015-9340-4

Rich, J. D., Colon, A. N., Mines, D., & Jivers, K. L. (2014). Creating learner-centered assessment strategies for promoting greater student retention and class participation. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00595

Rose, D. H., & Strangman, N. (2007). Universal design for learning: Meeting the challenge of individual learning differences through a neurocognitive perspective. *Universal Access in the Information Society*, *5*(4), 381–391. https://doi.org/10.1007/s10209-006-0062-8

Sarabi, M. K., & Gafoor, A. (2018). Student perception on nature of subjects: Impact on difficulties in learning high school physics, chemistry, and biology. *Innovation and Researches in Education*, *8*(1), 42–55.

Schnotz, W., & Kürschner, C. (2007). A reconsideration of cognitive load theory. *Educational Psychology Review*, *19*(4), 469–508. https://doi.org/10.1007/s10648-007-9053-4

Schüler, A., Scheiter, K., & Gerjets, P. (2013). Is spoken text always better? Investigating the modality and redundancy effect with longer text presentation. *Computers in Human Behavior*, *29*(4), 1590–1601. https://doi.org/10.1016/j.chb.2013.01.047

Sobrinho, N. D., & Souza, A. S. (2023). The interplay of long-term memory and working memory: When does object-color prior knowledge affect color visual working memory? *Journal of Experimental Psychology: Human Perception and Performance*, *49*(2), 236–262. https://doi.org/10.1037/xhp0001071

Sternberg, R. J., & Sternberg, K. (2011). *Cognitive psychology* (6th ed.). Wadsworth Publishing.

Stockwell, B. R., Stockwell, M. S., Cennamo, M., & Jiang, E. (2015). Blended learning improves science education. *Cell*, *162*(5), 933–936. https://doi.org/10.1016/j.cell.2015.08.009

Susiyawati, E., & Treagust, D. F. (2021). Students' visual literacy: A study from plant anatomy learning. *Journal of Physics: Conference Series*, *1747*(1), 012021. https://doi.org/10.1088/1742-6596/1747/1/012021

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*(4), 295–312. https://doi.org/10.1016/0959-4752(94)90003-5

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, *22*(2), 123–138. https://doi.org/10.1007/s10648-010-9128-5

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer New York. https://doi.org/10.1007/978-1-4419-8126-4

Sweller, J., van Merrienboer, J. J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251–296. https://doi.org/10.1023/A:1022193728205

Tannert, S., Eitel, A., Marder, J., Seidel, T., Renkl, A., & Glogger-Frey, I. (2023). How can signaling in authentic classroom videos support reasoning on how to induce learning strategies? *Frontiers in Education*, *8*, 974696. https://doi.org/10.3389/feduc.2023.974696

Van Kesteren, M. T. R., Krabbendam, L., & Meeter, M. (2018). Integrating educational knowledge: Reactivation of prior knowledge during educational learning enhances memory integration. *Npj Science of Learning*, *3*(1), 11. https://doi.org/10.1038/s41539-018-0027-8

Van Merriënboer, J. J. G., Kester, L., & Paas, F. (2006). Teaching complex rather than simple tasks: Balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology*, *20*(3), 343–352. https://doi.org/10.1002/acp.1250

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review*, *17*(2), 147–177. https://doi.org/10.1007/s10648-005-3951-0

van Riesen, S. A. N., Gijlers, H., Anjewierden, A. A., & de Jong, T. (2022). The influence of prior knowledge on the effectiveness of guided experiment design. *Interactive Learning Environments*, *30*(1), 17–33. https://doi.org/10.1080/10494820.2019.1631193

Wiersma, W. (1995). *Research methods in education: An introduction* (6th ed.). Allyn and Bacon.

Wynn, A. N., Pan, I. L., Rueschhoff, E. E., Herman, M. A. B., & Archer, E. K. (2017). Student misconceptions about plants – A first step in building a teaching resource. *Journal of Microbiology & Biology Education*, *18*(1), 18.1.40. https://doi.org/10.1128/jmbe.v18i1.1253

Xie, H., Wang, F., Hao, Y., Chen, J., An, J., Wang, Y., & Liu, H. (2017). The more total cognitive load is reduced by cues, the better retention and transfer of multimedia learning: A meta-analysis and two meta-regression analyses. *PLOS One*, *12*(8), e0183884. https://doi.org/10.1371/journal.pone.0183884

Zaid, S. N. L. B., & Iksan, Z. (2022). Systematic studies: Students' attitudes toward plants and plant science learning. *International Journal of Academic Research in Progressive Education and Development*, *11*(2), 188-198. https://doi.org/10.6007/IJARPED/v11-i2/12317

Zhu, J., Yuan, H., Zhang, Q., Huang, P.-H., Wang, Y., Duan, S., Lei, M., Lim, E. G., & Song, P. (2022). The impact of short videos on student performance in an online-flipped college engineering course. *Humanities and Social Sciences Communications*, *9*(1), 327. https://doi.org/10.1057/s41599-022-01355-6