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Offloading Through Emphasis Manipulation Sequencing During a Complex Learning Process in Cognitive Load and Learning Transfer

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Abstract: We propose a plan to facilitate the development of backward constituent skills within a complex learning process through the manipulation of emphasis sequencing. To achieve this, we utilized perceptual offloading cues as supportive information in emphasis sequencing, taking into consideration principles of information processing and cognitive loads. We examined changes in cognitive loads (intrinsic load, extraneous load, and germane load) as the complexity of each component increased. Our sample included 56 college students from Gyeonggi-do province who were tasked with completing a series of progressively complex PowerPoint functions, focusing on the acquisition of constituent skills. The experiments were conducted over five sessions, with cognitive load measurements taken after the fourth session was concluded. Learning transfer was evaluated by collecting and assessing the students' work at the end of the fifth session. The results demonstrated significant effects of emphasis manipulation sequencing in reducing cognitive load and facilitating the learning transfer process. The use of offloaded perceptual cues in this manner proved to be an effective strategy for enhancing the development of constituent skills learned through emphasis manipulation sequencing, while effectively managing and minimizing cognitive load in complex learning scenarios.

Keywords: *Complex learning, offloading, emphasis manipulation sequencing, cognitive load, learning transfer.*

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Introduction

Learners often have difficulty applying learned knowledge and skills in real-life problem-solving situations. Normally, learners tend to remember minimal relevant circumstances or context (Risko & Gilbert, 2016), and the total information recognized is difficult to memorize due to the brain's limited storage capacity (Chen et al., 2018; Sweller et al., 2011). According to cognitive load theory, learning failure is highly influenced by cognitive load when the amount of information exceeds the limited processing capacity of the brain. Thus, teaching plans that arrange information at a lower level of expertise may enable students to grasp the content temporarily, but the recurring challenge of applying what they have learned remains.

The goal of cognitive load theory is to minimize unnecessary cognitive load during the learning process to plan innovative and effective teaching processes that optimize the information processing ability of students (Chen & Kalyuga, 2020). In the past, studies of cognitive load focused on designing teaching plans by considering interactions between cognition and information structures (van Merriënboer & Sweller, 2005), and transforming unproductive cognitive resources into productive ones. However, recent cognitive load studies have expanded into investigating methods to control load (Paas & van Merriënboer, 2020) by considering the diverse range of effects that were revealed in Sweller et al. (2019). Teaching plans should incorporate appropriate strategies based on learning task type, degree of expertise, and learning environments, and partial adjustments based on the cognitive-load effect could suggest new, innovative teaching plans suitable for each given purpose (Paas & van Merriënboer, 2020).

Teaching plans should be flexible according to the learning situation, considering the principles of information processing and effect of cognitive load (Sweller, 2020). Traditional teaching methods are used to create teaching plans by compartmentalizing the interactions of knowledge, skill, and attitude, and present information in small units with low degrees of interaction among the constituents to minimize cognitive load. While this is an effective method to improve information recall (Choi et al., 2019), learning transfer might be poor or not happen at all (van Merriënboer & Kirschner, 2017). On the other hand, whole task sequencing based on the 4C/ID model, as suggested by van Merriënboer and

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Kirschner (2017), can enhance learning transfer for problem situations in teaching plans. This planning method is used in complex learning situations similar to actual, real-life problem solving processes, which are comprehensive states in which knowledge, skills, and attitude interact with each other, causing high degrees of cognitive load (Sweller et al., 2011). Therefore, teaching planning must focus on controlling cognitive load to improve learning transfer and aim to accomplish effective elaboration of the learning material.

On the other hand, emphasis manipulation sequencing is a teaching planning method that aims to facilitate complex learning by focusing on the constituent skill sets required for a given task class. This approach allows learners to engage in conventional tasks and was explored in studies such as Choi et al. (2019) and Frerejean et al. (2021). Planning personnel provide supportive information that corresponds to constituent skills, and the learner constructs a strategy to perform the task by referring to the supportive information provided. However, as the supportive information differs according to the task class and skill set, previously offered supportive information may not be useful when the learning sequence has moved forward. According to the transient information effect, elaboration becomes more difficult when information is provided in a complex manner for a longer period of time (Sweller, 2020). In addition, according to Risko and Gilbert (2016), prospect memory could result in errors when there is a time difference between the moment information is acquired and when the learned information is applied. In such a context, executing complex learning using emphasis manipulation sequencing could limit the elaboration of knowledge quickly obtained from supportive information, and as the task class progresses forward, the time delay could lead to errors in the learning process. Therefore, planning of emphasis manipulation sequencing should effectively elaborate supportive information in all constituent skills during the learning process.

We conducted this study to address several problems. First, as constituent skills increase, emphasis manipulation sequencing results in increased time gaps between the provision of supportive information and execution, causing the learner's memory of learned material to be erroneous. Therefore, it a necessary to devise a method that continuously elaborates upon supportive information while learning is still in progress. Second, non-permanent supporting information can lead to the integration and interaction of incomplete knowledge, skill, and attitudes during integrative information processing, emphasizing the necessity of optimizing the supportive information being provided.

The purpose of this study is to suggest a teaching planning method using emphasis manipulation sequencing to change the temporary information provided with a specific constituent skill into permanent information, so that learning the constituent skill set also results in elaboration of what has been learned. For this purpose, we applied offloading methods to supportive information in consideration of the information processing principle and cognitive load effect, so that the supportive information for each constituent skill provided by the instructor is converted into a record reconstructed by the learner. As a result, supportive information that has been converted to record form can be used when it is necessary to elaborate using previous supportive information, so that cognitive load is efficiently controlled and learning transfer can improve.

- Study Question 1. How does the offloading of supportive information through emphasis manipulation sequencing in complex learning affect cognitive loading?
- Study Question 2. How does the offloading of supportive information through emphasis manipulation sequencing in complex learning affect learning transfer?

Literature Review

Relationship Between Cognitive Processing and Learning

Cognitive load theory focuses on working memory capacity. Working memory is produced through the conscious act of translating new information into knowledge (Sweller et al., 1998). Such knowledge can be classified into facts, concepts, procedures, strategies, and beliefs in the context of learning (Mayer & Wittrock, 2006). However, working memory has limited capacity while information is processed and transformed into knowledge, and information that exceeds the capacity is removed from memory. Effective processing of working memory requires active cognition to understand and compare new information to existing information from previous memories. Mayer (2009) described the cognitive process of working memory as shown in Figure 1, and suggested that sensory memory, working memory, and long-term memory are effectively formed when knowledge from learning is selected, organized, and integrated.

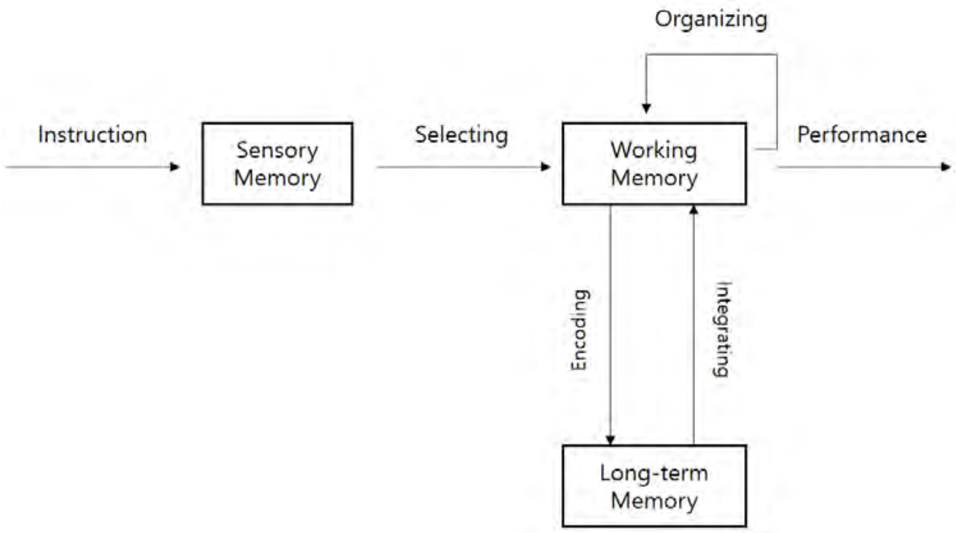

Figure 1. Cognitive Memory Process Proposed by Mayer (2009)

First, sensory memory recognizes information provided by vision and hearing, and the memory is stored as accurate visual and auditory images just after the information is perceived. Working memory is a temporary space for storing knowledge obtained from sensory memory, which is re-processed as a mental image in the form of pictorial or verbal representation (Mayer, 2014). Lastly, long term memory storage is where the memory processed from working memory is stored and allows memory to be stored continuously. Detailed perception processing transfers select information from sensory memory to the working memory area, organizing the perceived information to create a mental representation. Then, a mental representation is formed through active learning by being integrated with long-term memory (Mayer, 2011).

In perception processing, if too much information is being transferred temporarily, the working memory may be impeded by excessive cognitive load due to its limited capacity (Sweller et al., 2011). Normally, the number of information elements processed at one time in the working memory is 7, with a minimum of 5 and maximum of 9. The type of cognitive load that occurs when the number of information elements exceeds the maximum can be classified into two categories, intrinsic cognitive load caused by the structural difficulty of learning a task or content, and extraneous cognitive load, which happens due to the teaching process. To determine why intrinsic and extraneous cognitive load occur it is necessary to examine whether they are due to elements making up the learned information as well as the interactivity of the elements (Chen et al., 2018). An information element refers to a discrete smaller unit of information that is considered low order information. On the other hand, the interactivity of elements represents higher order information that necessitates connecting these individual elements together in a conceptual manner. According to this principle, if the learning task or the content are complex or abstract, the difficulty of the task is high and there is higher interactivity among elements. In addition, when an instructor presents information that is not relevant to the learning task or content, or presents too much information at once, this could result in unnecessary interactions among elements. Therefore, to prevent excessive cognitive load, the teaching plan must be presented strategically by considering the relationship between the information being presented and the working memory associated with it.

Learning Offloading and Working Memory

1) Concept of Offloading

Offloading is a method to supplement and assist working memory by substituting something to be remembered with an external stimulus (Risko & Gilbert, 2016). This is a cognitive control method that changes knowledge processed by internal working memory into external information, and lets the knowledge be processed through the internal working memory when it is the time to recall it. A previous study (Goldin-Meadow et al., 2001) showed that younger learners use their fingers to perform simple calculations. Studies show that allowing extra working memory capacity helps learners to focus on learning activities. Risko and Dunn (2015) also suggested that offloading could help learners to accurately perform short term memory tasks. As such, offloading could disperse cognitive processing normally completed within the working memory to external areas to increase working memory capacity, and after active processing, this method can support effective problem solving by integrating information and constructing an efficient cognitive process.

Risko and Gilbert (2016) introduced three distinct methods of offloading, namely the body, world, and meta-cognition. First, the body is used to decrease conscious effort in recalling. If a sentence is presented in a diverse direction rather than a single, regular direction, the learner might experience cognitive difficulties in the internal normalization process. To resolve this issue, the learner automatically corrects their actions and cognitive processes by applying external normalization. For example, when a person sees a sentence that is tilted at a 45-degree angle, they tilt their head instead of the sentence itself. As such, using the body enhances recognition by sensory memory when it is difficult to process information obtained from sensory memory while storing knowledge in working memory. Second, using the surrounding environment temporarily places the information to be internally processed outside, thus reducing intrinsic cognitive load. Methods that transfer cognitive load to the surrounding environment can be classified as prospective memory or transactive memory. Prospective memory acts upon intent, and lets the user remember the intention using environmental cues such as Post-It memos, timers, and highlights. The concept of transactive memory is an expansion of the general transactive memory concept into human-technology transactive memory systems, enabling information provided by a technology to be used in problem-solving. This is similar to using calculators to minimize the use of component skills, as presented in Mayer and Wittrock (2006). Offloading using the surrounding environment withdraws knowledge that should be processed during the working memory process by using relevant cues or techniques to aid memory and uses the increased brain capacity in problem-solving by lowering the processing burden on the working memory. Third, metacognition decides whether to offload when a person chooses a strategy for problem-solving. Individuals are more likely to externalize offloading if they have negative metacognitive self-evaluations, believing they will not be able to remember information (Meyerhoff et al., 2021). Therefore, beginners are more likely to choose offloading as a problem solving strategy than experts.

2) Relationship between Offloading and Working Memory

Working memory processing by offloading is described in Figure 2 and is integrated with the working memory processing steps proposed by Mayer (2009). The learner systematizes information provided by the instructor using sensory memory, and if the self-evaluation through metacognition is positive in long-term memory when the learning experience is being retrieved, the learner experiences an internal elaboration process. Then, the learner searches for similar knowledge based on existing experience in the long-term memory, and the knowledge will be coded through an elaboration process that integrates it with newly obtained knowledge, resulting in better performance. On the other hand, if the learner's metacognitive self-evaluation is negative, then the information is offloaded and becomes a cognitive cue in the outside environment that is used as a resource when the working memory is being used (Boldt & Gilbert, 2019). If the learner recognizes that the information is overly complex or difficult to understand during internal elaboration, the information will also be integrated into the outside environment as a cognitive cue without intrinsic cognitive processing to substitute for working memory processing (Dunn & Risko, 2015).

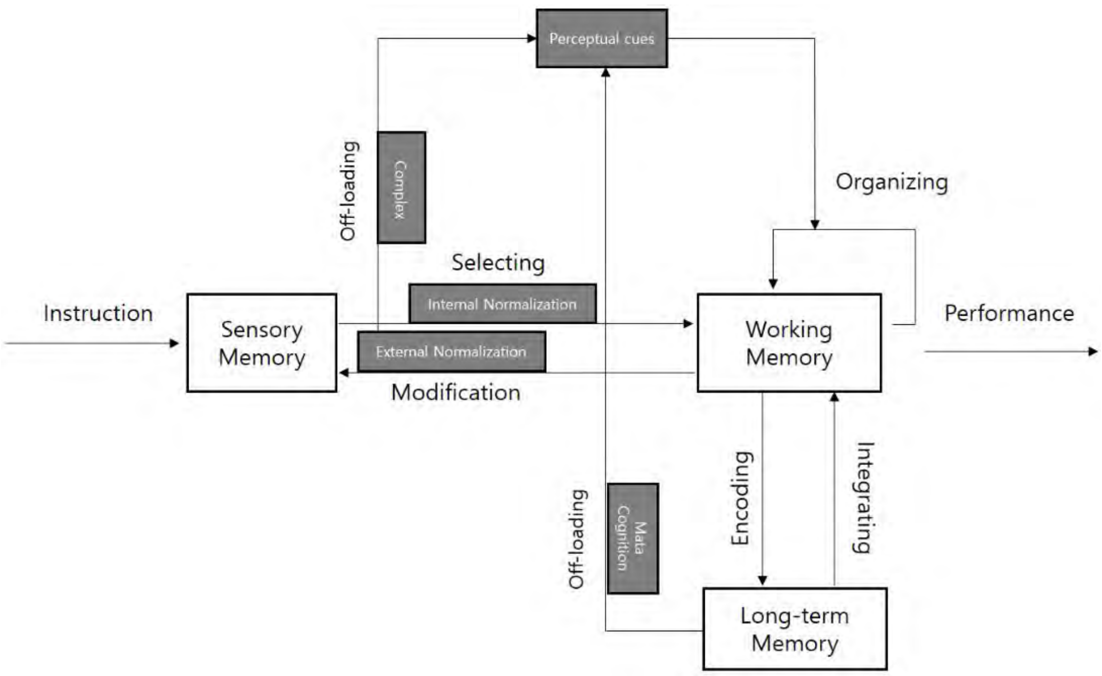

Figure 2. Offloading Methods and Processes for Using Working Memory

In cognitive offloading, working memory processing employs different strategies for internal and external offloading. Intrinsic cognitive load encompasses the perception of information to be learned through sensory memory, along with metacognitive judgments regarding the likelihood of successful learning. If the learner perceives a negative potential for learning, they will employ cognitive cues from the external environment based on principles of offloading (Meyerhoff et al., 2021). Alternatively, before the information captured by the sensory memory is chosen and processed by working memory, if the information is thought to be highly complex and difficult during the stage when the learner consciously regulates the learning process, the information can be retrieved using cognitive cues. Likewise, extraneous cognitive load in the learning process could compel the learner to replace necessary concepts or principles in learning with an external tool or skills to decrease cognitive load (Mayer & Wittrock, 2006) and allow mental resources to be concentrated in necessary areas to facilitate higher levels of understanding (Weis & Wiese, 2019).

A successful experience with cognitive cues during offloading can enhance the credibility of retrieved information (Risko & Gilbert, 2016), thereby increasing the inclination to utilize cognitive cues without adding to the cognitive load (Weis & Wiese, 2019). Under normal learning conditions, when components related to the domain of intrinsic cognitive load are offloaded, the learner loses the ability to consciously process the information, and therefore there is lack of ability to learn. However, complex learning allows concerted integration and synergy of knowledge, skills, and attitudes through actual performance, rather than obtaining the knowledge from an instructor (van Merriënboer & Kirschner, 2017). Therefore, using offloaded information to allow students to perform a conventional task according to sequencing methods may help learners to successfully perform tasks by elaborating the memory component of long-term memory as well as offloaded external components of information in the working memory. Consequently, complex learning processes based on offloading of cognitive load begin with a conventional task that consists of low-level interactions among units that can be offloaded, and progressively increase in complexity. Then, as sequencing progresses, the curriculum should be constructed in a way that ensures complete cognitive processing and elaboration as cognitive cues that were offloaded are integrated from external to internal environments.

Emphasis Manipulation Sequencing and Facilitating Elaboration

1) Principle of Emphasis Manipulation Sequencing

Emphasis manipulation sequencing is a method of whole task sequencing for complex tasks. As shown in Figure 3, a whole task consists of the task situation according to constituent skills and allows students to gradually perform complete, real-life tasks. This method becomes more complex when cognitive strategies and mental models are different for each skill set, and the forward progression of skill sets increases the number of skill components and complicates interactions among components.

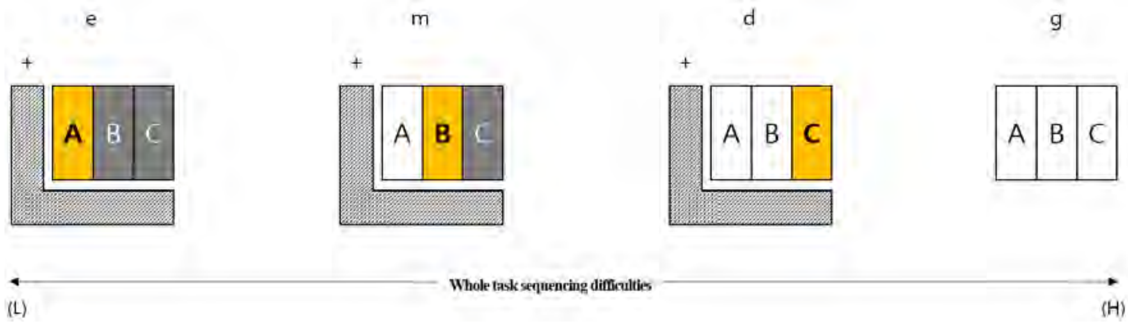

Figure 3. Emphasis Manipulation Sequencing Method

* : Support and instruction, : Emphasized constituent skill set, : Conventional task skill sets, : Conventional task to-be-performed skill sets, e (easy): task with "easy" difficulty , m (medium): task with "medium" difficulty, d (difficult): task with "difficult" difficulty, g (general): general tasks

In emphasis manipulation sequencing, learners only need to perform general tasks requiring focused constituent skills. Therefore, learners do not need to invest cognitive effort to learn constituent skills, because emphasis manipulation sequencing is constructed to aid effective learning by dispersing the mental effort necessary for a complex task into different constituent skills, and lets the learner focus on specific constituent skills one by one. Although this method is constructed so that complexity increases gradually in terms of information processing and cognitive load, it can be managed to avoid exceeding the learner's information processing capacity by focusing on each part of the whole constituent skillset individually during the learning process.

2) Emphasis Manipulation Sequencing and Cognitive Offloading

When implementing emphasis manipulation sequencing, it is important for instructors to acknowledge that there exists a temporal gap between the acquisition of specific constituent skills in the past and their interaction and progression within the constituent skill group during the learning process. Thus, it is crucial to design the learning process in a manner that allows for the elaboration of previous constituent skills while acquiring the targeted constituent skill. The cognitive strategy and mental models involved are processed within the learner's cognition, becoming synchronized and activated when engaging in relevant tasks. However, as the task class advances, there may be unactivated task components and interactions among them, resulting in time gaps between prior learning and current learning tasks, which can potentially distort the learner's memory (Risko & Gilbert, 2016). Therefore, to prevent un-activated components and interactions being distorted and causing misunderstanding, the information that was already understood in the current task class must be offloaded and retrieved, so that the learner can repeatedly use that information even if learning progresses forward.

Offloaded supporting information is a cognitive cue to perform a conventional task within the focused constituent skill set as well as the skill set that has progressed forward and is in the form of external data that the learner constructs when supporting information is received. As an offloading method, Mayer and Wittrock (2006) proposed replacing things that cause cognitive load with a tool that can be used by learners that minimizes components and constituent skills necessary for the problem-solving situation. Such minimizing of cognitive load could be manifested as many types of external items, such as handwritten notes, sketches, or documents (Risko & Gilbert, 2016; Sweller, 2020).

A cognitive cue fosters successful learning when working on a specific conventional task and promotes elaboration as a bridge to integrate existing knowledge and newly introduced knowledge when performing a task that has progressed forward. As a result, as shown in Figure 4, our method proposes creating a cognitive cue when supporting information is provided, before the learner is asked to perform a conventional task with a specific constituent skill set and the forward-progressed skill set utilizing the cue.

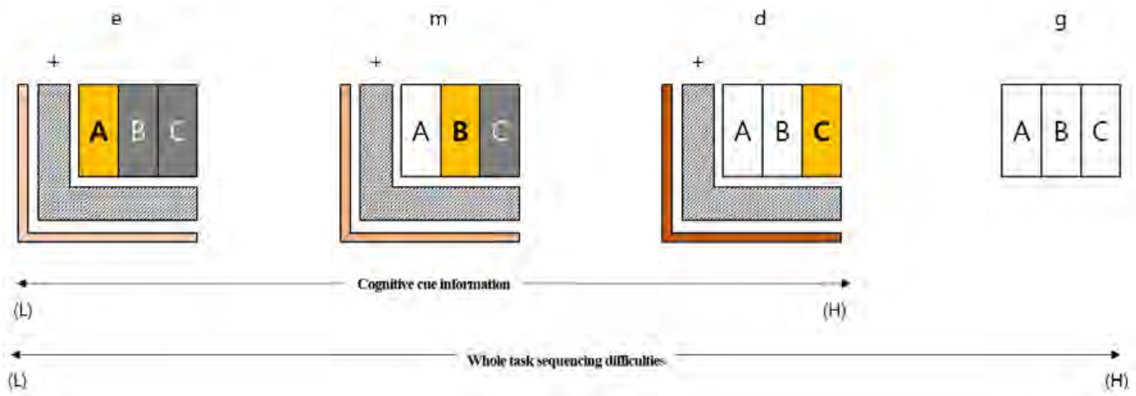

Figure 4. Utilizing Cognitive Cues Based on Emphasis Manipulation Sequencing and Offloading

: Support and instruction, : Emphasized constituent skill set, : Conventional task skill sets, : conventional task to-be-performed skill sets, : cognitive cue for constituent skill set A : cognitive cue for constituent skill set A and B : cognitive cue for constituent skill set A, B, and C; e (easy): task with "easy" difficulty , m (medium): task with "medium" difficulty, d (difficult): task with "difficult" difficulty, g (general): general tasks

3) Offloading Methods and Learning Transfer

Learning transfer involves coding and elaborating knowledge, applying knowledge to a problem-solving situation, and using reasoning skills to solve real-life problems (Schunk, 2012). In a complex learning process, the successful transfer of learning necessitates the appropriate adjustment of both non-circular aspects, such as cognitive strategy and mental models, and circular aspects, including cognitive patterns and pre-existing knowledge, to real-world problem-solving situations (van Merriënboer & Kirschner, 2017). However, complex learning involves very complex interactions among knowledge, ability, and attitude, causing high levels of cognitive load (Sweller et al., 2011). Upon forward progression, emphasis manipulation sequencing should effectively elaborate knowledge, ability, and attitudes that are to be newly learned.

Applying offloading methods, using cognitive cues, and remembering action intentions helps learners to remember knowledge more effectively when performing a delayed task, helping the knowledge to be coded and integrated (Boldt & Gilbert, 2019). According to reflexive association theory, the stronger the connection between cues and intentions, the stronger the association. Upon perceiving a cue, the intended action is represented in the learner's consciousness (Brandimonte et al., 2014). As shown in Figure 4 cognitive cues play crucial roles in shaping learners' intentions and linking them to future planned actions. By aiding learners in remembering the intentions behind delayed actions, cognitive cues facilitate the elaboration and integration of knowledge. This is particularly evident in emphasis manipulation sequencing, where learners engage in conventional tasks, allowing for effective knowledge application and integration.

Methodology

Study Subjects

A total of 63 students from years 1 through 4 at S university, a 4-year institution located in Gyeonggi-do province, South Korea, participated in this study. Microsoft PowerPoint was selected as the target task for this study due to its significance in college assignments and external competitions for Korean college students. Proficiency in PowerPoint is considered essential for successfully completing assignments and competing in various academic events. At the end of the study, 56 students remained in the sample (Table 1), as 2 students did not answer the cognitive load survey, and 5 did not submit their final task. Out of the total sample, 16 students (28.6%) were male, while 40 students (71.4%) were female. The distribution of students across the academic years was as follows: 21 students (37.5%) were in their first year, 14 students (25%) were in their second year, 12 students (21.4%) were in their third year, and 9 students (16.1%) were in their fourth year. The study and necessary information about the study were introduced and explained to students prior to the beginning of the study, and data collection and analysis were performed after obtaining consent from students to use their personal information for this study.

Table 1. Demographic Characteristics of Final Study Participants by Group

Classification		Control group (persons/%)	Treatment group (persons/%)	Overall participants (persons/%)
Sex	Male	9 (16.1%)	7 (12.5%)	16 (28.6%)
	Female	18 (32.1%)	22 (39.3%)	40 (71.4%)
Year of Study	1st year	11 (19.6%)	10 (17.9%)	21 (37.5%)
	2nd year	6 (10.7%)	8 (14.3%)	14 (25%)
	3rd year	6 (10.7%)	6 (10.7%)	12 (21.4%)
	4th year	4 (7.1%)	5 (8.9%)	9 (16.1%)

Study Design

The experiment was designed to reveal the effects of combining emphasis manipulation sequencing with offloading on cognitive load and learning transfer in a complex learning environment. The detailed study design is shown in Figure 5. The sequencing method was used as the independent variable in this study, while cognitive load and learning transfer served as the dependent variables.

The independent variable in this study consisted of two types of sequencing methods: emphasis manipulating sequencing and a combined method of supporting information offloading and emphasis manipulating sequencing. The control group included students who learned content by existing emphasis manipulating sequencing methods, and were asked to perform a conventional task while the emphasis on each constituent skill set was different, as shown in Figure 3. The treatment group was exposed to a combined method of emphasis manipulation sequencing and supporting information offloading. This approach allowed the participants to utilize supporting information after offloading it during the forward progression of learning content, as shown in Figure 4. The dependent variables included intrinsic cognitive load, extraneous cognitive load, and germane load. These variables were measured to assess the cognitive load experienced by the participants, which can be influenced by the task difficulty and the level of immersion in the task. Additionally, learning transfer was evaluated by assessing the application of the learned content through a real-life problem-solving exercise conducted at the conclusion of the study.

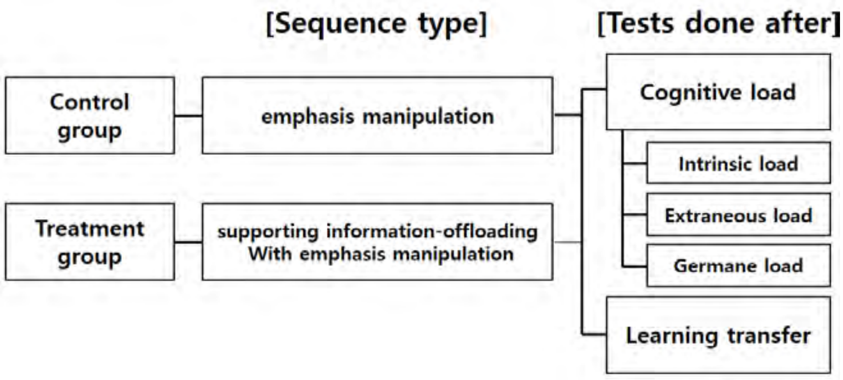

Figure 5. Detailed Study Design

Offloading Method for Learning Tasks and Supporting Information

The learning task assigned to the college students involved creating a PowerPoint presentation to introduce themselves. The study was designed so the construction of objectives and skills would be approached differently by different participants. The task of creating a PowerPoint presentation to introduce oneself is considered a real-life task with non-circular aspects, as highlighted by Choi et al. (2019). This task encompasses various abilities that students can acquire and improve upon, and it requires a higher degree of interaction among these abilities compared to other tasks. Consequently, more cognitive effort is necessary to effectively elaborate on the learned information in this task.

As learning progresses, the use of emphasis manipulation sequencing may introduce challenges in terms of cognitive load and hinder learning transfer due to potential unwanted interactions between supporting information and the constituent skills that learners have developed throughout the learning process. However, by effectively incorporating supporting information during task performance, learners may reduce the intrinsic and extraneous cognitive load associated with the task, while simultaneously increasing the germane load. This strategic allocation of cognitive resources can lead to improved learning outcomes and increased learning transfer, allowing learners to apply their acquired knowledge and skills in new contexts effectively. To control cognitive load and increase learning transfer, the information presented should be integrated and coordinated at appropriate times. Consequently, the supporting information offloading - emphasis manipulation sequencing method rephrases supporting information in the learner's terms, and combining cognitive processing methods is necessary to perform conventional tasks using the excess cognitive space obtained through offloading. By integrating offloaded information in forward-progressed constituent skills and supporting information in an elaborated form, this method can also effectively manage cognitive load caused by gradually increasing complexity as learning progresses.

The task class used in this study for emphasis manipulating sequencing is shown in Table 2. The tasks included creating introductory presentations focusing on 1) text functions of PowerPoint, 2) shape functions of PowerPoint, and 3) animation functions of PowerPoint; and 4) creating an introductory presentation for which the supporting information comprised instructions teaching the focused skills for each task class, meaning text functions, shape functions, and animation functions. The method for offloading supporting information used a resource created by the learners as shown in Figure 6, and reproducing data into cognitive cues, shown in Table 2, to control cognitive load during the learning process. To elaborate further, the learning process involved specific steps. First, learners were instructed to offload and reconstruct information related to the text functions they had previously learned, with the intention of utilizing this reconstructed information in future tasks. This reconstructed information was then used to perform conventional tasks in the first task class. Second, in the second task class, learners focused on acquiring knowledge related to utilizing shapes in PowerPoint. They added this new information to the reconstructed information resource from the previous task class, thus expanding and refining their knowledge. The reconstructed information was then utilized in the second task. Third, in the third task class, learners reconstructed the information learned in the third session, which specifically focused on the animation function in PowerPoint. This newly acquired knowledge was added to the existing reconstructed information from the previous task class. The learners then utilized this expanded reconstructed information resource for the third task. However, the fourth task was distinct from the previous tasks. In this task, students were required to perform a conventional task without any support or additional instruction. They did not consult any offloaded resources, and instead relied solely on their acquired knowledge and skills. Overall, this learning process involved gradual reconstruction and integration of information, allowing learners to build upon their prior knowledge and apply it effectively in subsequent tasks.

Table 2. Constituent Skills for Each Task Class and Detailed Subject Areas of Tasks

Session number	Task difficulty	Sequence type	Task class	Constituent skills			Cognitive cues	Task performance	Detailed subjects of each task class
				Text functions	Shape functions	Animation functions	Construction of supporting information and offloading resources	Conventional tasks	
1	e	Emphasis manipulation sequencing	Creating an introductory presentation focusing on the text functions	●				■	1st week introduction of material from the subject area the student is majoring in
		Supporting information offloading - Emphasis manipulation sequencing		●			◎	◎ ■	
2	m	Emphasis manipulation sequencing	Creating an introductory presentation focusing on the text functions		●			■	Introductory material on ocean environmental preservation
		Supporting information offloading - Emphasis manipulation sequencing			●		▲(◎)	▲(◎) ■	
3	d	Emphasis manipulation sequencing	Creating an introductory presentation focusing on the animation functions			●		■	Introducing a specific application
		Supporting information offloading - Emphasis manipulation sequencing				●	▼(◎+▲)	▼(◎+▲) ■	

Table 2. Continued

Session number	Task difficulty	Sequence type	Task class	Constituent skills			Cognitive cues	Task performance	Detailed subjects of each task class
				Text functions	Shape functions	Animation functions	Construction of supporting information and offloading resources	Conventional tasks	
4	g	Emphasis manipulation sequencing	Creating a presentation					■	Resources for college freshmen
		Supporting information offloading - Emphasis manipulation sequencing						■	
5	g	Emphasis manipulation sequencing	Creating a presentation					■	Creating a personal profile
		Supporting information offloading - Emphasis manipulation sequencing						■	

* e (easy): task with “easy” difficulty , m (medium):task with “medium” difficulty, d (difficult): task with “difficult” difficulty, g (general): general tasks, ◎: Offloading resources for 1st session task, ▲: Offloading resources for 2nd session task, ▼: Offloading resources for 3rd session task

The constituent skill sets and skills involved were decided upon after consulting with two college professors with over 10 years of experience in teaching basic PowerPoint courses. The supporting material consisted of videos developed by an individual specializing in visual design who currently runs a business focusing on text, shapes, and animations applicable to PowerPoint. To determine the validity of supporting information for each constituent skill, a pilot test was performed with one 1st-year student, two 2nd-year students, one 3rd-year student, and two 4th-year students at S university. The pilot study indicated that there was not enough time to retrieve supporting information as well as perform the task, so we increased the retrieval time for supporting information from 10 minutes to 15 minutes, and the time allotted for task performance from 20 minutes to 30 minutes.

Consequently, to learn how to create an introductory PowerPoint presentation, both control and treatment groups presented supporting information in a deductive manner according to each constituent skill set, and the whole task was performed differently according to the sequencing methods used. In both groups, the supporting information was provided as a video showing the process of making an introductory presentation using text, shapes, and animation constituent skill sets prior to performing the task, and the treatment group was asked to take notes regarding what they understood after performing conventional tasks for each class, thereby producing a record of what they understood, as shown in Figure 6.

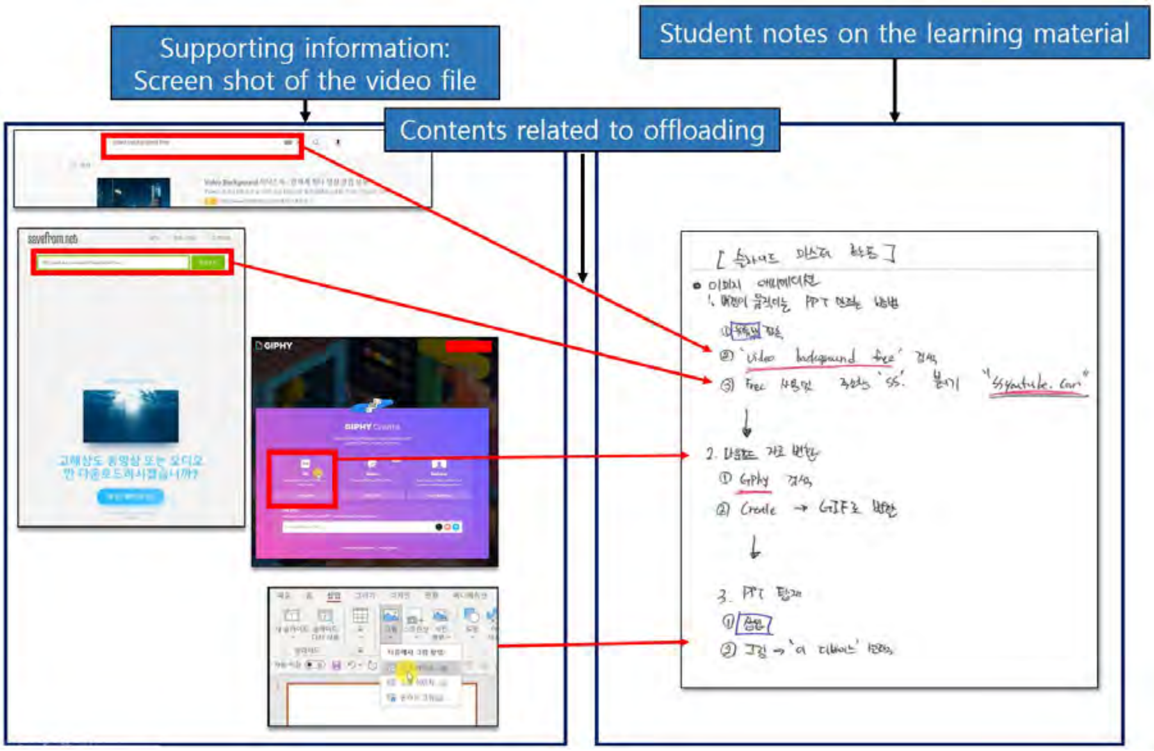

Figure 6. Example of Supporting Information (Left) and Student Notes Showing Offloaded Content (Right) Used in Supporting Information-Offloading Emphasis Manipulating Sequencing

Testing Tools

1) Cognitive Load Test

The cognitive load test utilized a tool developed by Leppink et al. (2013), which enabled accurate measurement of each type of cognitive load. The original English questionnaire was forward translated into Korean by the researchers, and the Korean version of the instrument was reviewed for translation accuracy and cultural differences by two doctoral students in educational technology. The revised Korean version of the questionnaire was then backward translated into English by a Korean American who is a native English speaker and fluent in Korean. The backward translated questionnaire was then compared to the original English questionnaire by two American doctoral students majoring in educational technology to ensure that there were no changes in meaning. The test comprised 10 questions categorized into three distinct types. Three questions were dedicated to assessing intrinsic cognitive load, another three questions focused on evaluating extraneous cognitive load, and the remaining four questions were designed to gauge germane load. The students answered on a scale of 0 to 10, where 0 indicated “not at all true” and 10 meant “very much true.” Cronbach’s alpha for each type of cognitive load were .713, .799, and .74, respectively. As students performed complex tasks, the tasks increased in complexity when more knowledge was being obtained (Sweller et al., 2019). Therefore, we measured cognitive load after completing the final learning task, as that was when the knowledge, ability, and attitude were expected to be the most well-integrated and coordinated.

2) Learning Transfer Test

The learning transfer test required learners to use a checklist of utilization of sub-functions in each constituent skill set learned in the study. As shown in Table 3, there were a total of 15 checklist items, including 5 questions for the text-related constituent skill set, 5 questions for the shape-related constituent skill set, and 5 questions for the animation-related constituent skill set. If the final task used a specific function that corresponded to each item on the checklist the student gained a point; if it did not, the student would get 0 points for the specific item. In complex learning, learning transfer is defined as being able to utilize a problem solving method in real-life situations through the integration and coordination of learned knowledge, ability, and attitude (van Merriënboer & Kirschner, 2017). As such, the students were asked to create a personal profile using what they had learned after the learning sessions concluded. The learning transfer test was evaluated by a doctoral student in an educational engineering PhD program and the researcher in charge of the program.

Table 3. Checklist for Each Constituent Skill to Assess Learning Transfer (Based on PowerPoint 2016)

Classification	**Constituent skill set**		
	Text	**Shapes**	**Animation**
1	Paragraph function	Shape fill and line functions	Slide screen transitioning
2	Text fill and outline function	Shape effects	Timing function
3	Text effects	Editing and/or combining shape(s)	Using animation
4	Using a text box (adjusting the size/margin)	Using SmartArt	Using advanced animations
5	Using WordArt	Slide Master function	Using GIF files

Study Procedures

The procedures for this study are shown in Table 4. In sessions 1 through 4 students were asked to perform learning tasks for each constituent skill based on the sequence type and level shown in Table 2. For the last session (5th session), students were evaluated using task results made using the skills learned in previous sessions. First, study groups were allocated on a first-come, first-served basis, with students chosen in the order of signing up for the learning program. The study comprised two groups: a control group (n=27) that utilized emphasis manipulation sequencing alone, and a treatment group (n=29) that employed the supporting information-offloading emphasis manipulation sequencing method. Second, learning was carried out for 2 weeks over a span of 4 classes, with 2 classes being carried out per day per week, meaning there were one-week gaps between the 1st/2nd and 3rd/4th sessions. The cognitive load test was performed using an online link distributed immediately after the conclusion of the 4th class. Third, to evaluate learning transfer, a fifth teaching session took place three months after the fourth session, as recommended by Axtell et al. (1997). During this session, students were instructed to complete a conventional task that required them to apply all of the skills they had acquired throughout the five sessions. The final task results were collected and assessed immediately upon completion of the program.

Table 4. Study Process

Study Progress	**Session number**	**Activities by sequencing method**		**Time spent**
		Emphasis manipulation sequencing	**Supporting information-offloading emphasis manipulation sequencing**	
Performing Learning Tasks	Session 1 To Session 3	Explanation given for the study process		5 minutes
		Watching recorded video containing supporting information		15 minutes
			Taking notes while watching video	
		Performing given tasks – creating a PowerPoint presentation		30 minutes
		Submission of work		2 minutes
	Session 4	Performing given tasks – creating a PowerPoint presentation		30 minutes
		Submission of work		2 minutes
		Cognitive load test		3 minutes
Evaluation of learning	Session 5	Performing a conventional task – self-introduction presentation		30 minutes
		Submission of work		2 minutes

Analysis

The independent variable of this study was sequencing type, and the dependent variables of this study were cognitive load and learning transfer. Differences in the dependent variables according to sequencing type were assessed using independent samples t-tests. Data analysis was performed using SPSS 21.0, with the significance level set at .05.

After excluding outliers among the participants, cognitive load assessment data (intrinsic, extraneous, and germane cognitive load) and learning transfer assessment data from 56 participants were analyzed. The normality of the data was verified before conducting independent samples t-tests. The Shapiro-Wilk test indicated that the dependent variables had p-values greater than .05, suggesting that the data were normally distributed (Razali & Wah, 2011).

Results

Cognitive Load Analysis According to Sequencing Type

Analyses pertaining to study question 1, which examines differences in cognitive load based on sequencing type, are presented in Table 5. The assumption of normality for independent samples t-tests was assessed separately for three components of cognitive load: intrinsic cognitive load, extraneous cognitive load, and germane load. Levene's test was conducted to verify normality. Results indicated that all three categories exhibited insignificant departures from normal distributions (*p*=.566, *p*=.822, *p*=.899, respectively) at a significance level of .05.

Table 5. Cognitive Load Based on Different Sequencing Methods among Study Groups

Dependent variable	Groups	Case number	Levene's test		t	M	SD	p	ES (d)
			F	p					
Intrinsic cognitive load	Emphasis manipulation sequencing	27	.333	.566	2.16	16.89	1.31	.035*	.08
	Supporting information-offloading emphasis manipulation sequencing	29				16.17	1.17		
Extraneous cognitive load	Emphasis manipulation sequencing	27	.051	.822	2.37	17.93	1.27	.021*	.09
	Supporting information-offloading emphasis manipulation sequencing	29				17.14	1.22		
Germane cognitive load	Emphasis manipulation sequencing	27	.016	.899	-3.86	29.52	1.22	.000***	.22
	Supporting information-offloading emphasis manipulation sequencing	29				30.76	1.84		

* p <.05, ** p <.01, *** p <.001

The cognitive load types (intrinsic, extraneous, and germane) exhibited significant differences between sequencing methods. In terms of intrinsic cognitive load, the treatment group utilizing supporting information-offloading emphasis manipulation sequencing (M=16.17, SD=1.17) demonstrated a .72-point reduction compared to the control group employing emphasis manipulation sequencing alone (M=16.89, SD=1.31). This difference was statistically significant (t(54)=2.16, *p*=.035), with a small effect size of *d*=.08. Regarding extraneous cognitive load, the treatment group using supporting information-offloading emphasis manipulation sequencing (M=17.14, SD=1.22) exhibited a .79-point decrease compared to the control group using emphasis manipulation sequencing alone (M=17.93, SD=1.27). This difference was also statistically significant (t(54)=2.37, *p*=.021), with a small effect size of *d*=.09. Finally, germane cognitive load was found to be 1.24 points higher for the treatment group using supporting information-offloading emphasis manipulation sequencing (M=30.76, SD=1.84) compared to the control group using emphasis manipulation sequencing alone (M=29.52, SD=1.22). This difference was statistically significant (t(54)=-3.86, *p*<.001), with a moderate effect size of *d*=.22.

Learning Transfer According to Sequencing Type

Analyses regarding study question 2 evaluated differences in average learning transfer for each constituent skill according to sequencing type, as shown in Figure 7. The text (M=4.45), shapes (M=4.1), and animation constituent skill sets (M=3.24) showed higher learning transfer in the treatment group than the control group (M=4.15 for text constituent skill set, M=3.81 for shapes constituent skill set, and M=2.7 for animation constituent skill set) by .3, .29, and .54, respectively.

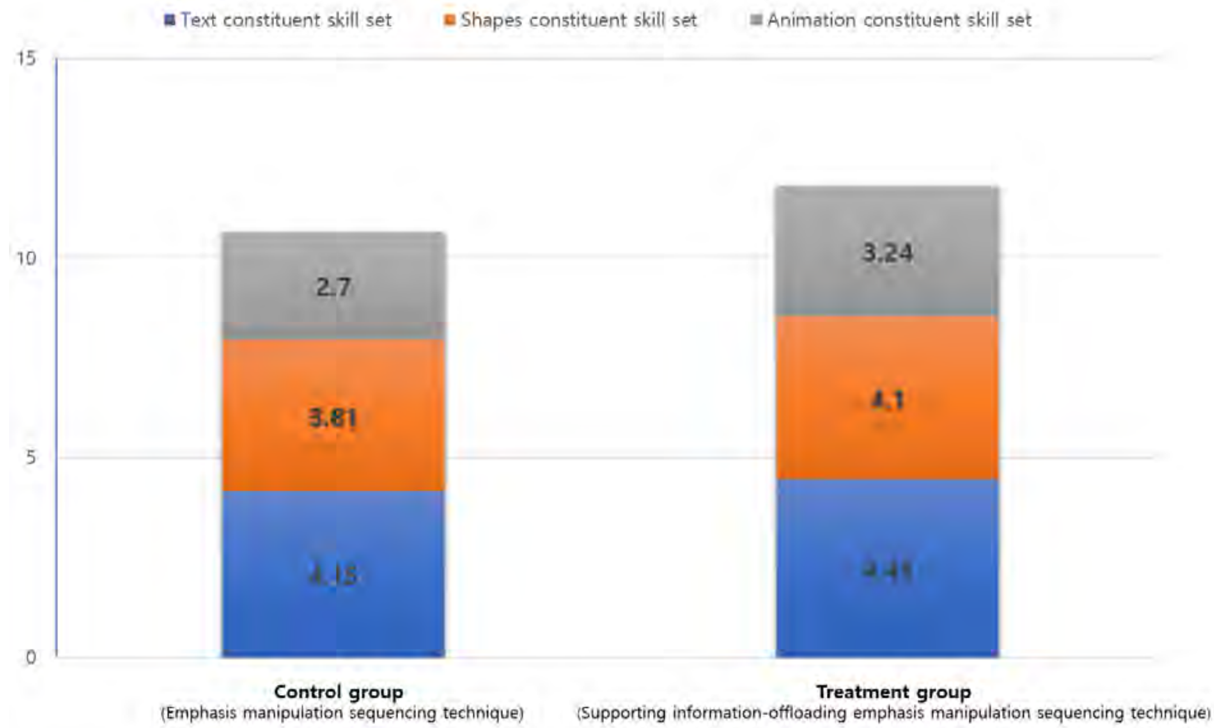

Figure 7. Average Learning Transfer for Each Skill Set by Study Group Based on Sequencing Type

Average total learning transfer based on sequencing type is shown in Table 6. The assumption of normal distributions in learning transfer data necessary to perform independent samples t-tests was verified using Levene's test. At a significance level of .05, no learning transfer categories differed significantly between study groups (*p*=.689), thus satisfying the prerequisite of normality for independent samples t-tests.

Table 6. Learning Transfer Based on Different Sequencing Methods Among Study Groups

Dependent variables	Groups	Case number	Levene's test		t	M	SD	p	ES(d)
			F	p					
Learning transfer	Emphasis manipulation sequencing	27	.162	.689	-3.36	10.67	1.3	.001**	.17
	Supporting information-offloading emphasis manipulation sequencing	29				11.79	1.21		

* p <.05, ** p <.01, *** p <.001

There were significant differences in learning transfer between groups using different sequencing methods. Specifically, the treatment group using supporting information-offloading emphasis manipulation sequencing (M=11.79, SD=1.21) was 1.12 points higher on average than the control group using emphasis manipulation sequencing alone (M=10.67, SD=1.3), and the difference was statistically significant (t(54)=-3.36 *p*=.001). The effect size was *d*=.1, verifying the actual significance of the data.

Discussion

In this study, we examined the impacts of supporting information-offloading and emphasis manipulation sequencing on the elaboration of knowledge in a complex learning setting, as well as its effects on cognitive load (intrinsic, extraneous, and germane load) and knowledge transfer. The task assigned to participants involved creating a PowerPoint presentation that focused on text, shapes, and animation functions. Offloading was carried out by creating notes about the learning material based on the sequencing method, which transformed the supporting information into a cognitive cue that could be retrieved later. The results of our study indicated that the combined use of supporting information, offloading, and emphasis manipulation sequencing methods during the execution of a conventional task enabled learners to effectively manage cognitive load and attain meaningful levels of learning transfer.

The Effect of Sequencing Type on Cognitive Load

When used in a complex learning process, the combination of supporting information-offloading and emphasis manipulation sequencing had more positive impacts on intrinsic, extraneous, and germane cognitive load than the use of emphasis manipulation sequencing alone. In emphasis manipulation sequencing, learners focus on learning central constituent skills and work on cultivating such skills while performing a conventional task, thus gradually expanding the problem area. In other words, a complex task requires a very high level of integration and coordination of knowledge, ability, and attitude, while also requiring high levels of interaction among an increasing number of constituents. In emphasis manipulation sequencing, forward progress typically entails the addition of constituents and increased connections and interactions among constituents to perform a given task, thus causing increase in intrinsic load. However, as proposed by previous studies (Boldt & Gilbert, 2019; Risko & Gilbert, 2016), offloading by externally normalizing supporting information helps control the number of constituents as well as their interactions in the learners' working memory.

Learners also experience lower germane cognitive load when a conventional task with higher complexity causes working memory to exceed its capacity, interfering with the learning process (van Merriënboer & Sweller, 2010). However, we found that using offloaded notes that were created during the learning process increases learner concentration and facilitates the learning process. As shown by Goldin-Meadow et al. (2001), decreasing the use of working memory helps learners to effectively focus on learning activities. At the same time, Weis and Wiese (2019) showed that cognitive cues that were exported to and retrieved from the external environment were closely linked to task intentions, providing clear evidence of the effective utilization of resources.

The Effect of Sequencing Type on Learning Transfer

In a complex learning process, supporting information-offloading used with emphasis manipulation sequencing gradually improves learning transfer for each constituent skill compared to emphasis manipulation sequencing used alone. Earlier studies (Sweller et al., 2011; van Merriënboer & Sweller, 2010) showed that elaborated learning processes combined intrinsic cognitive loads created by interactions among the constituents and lowered the complexity of the task, allowing the learner to experience meaningful learning by making more space for working memory. As such, allowing learners to use offloaded cognitive cues created to store supporting information decreased complexity by letting learners repeatedly perform the conventional task. In addition, by using offloaded cognitive cues, the higher-level interactions enabled the integration and coordination of higher-level interactions among the skills to be learned within working memory, facilitating the optimal management of resources.

Conclusion

In this study the learners were told to choose and retrieve resources and to use the resources for performing a conventional task. Contrary to the findings of a previous study (van Merriënboer et al., 2003) that suggested providing a learning resource during task performance increases extraneous cognitive load, we found that providing such resources was helpful for decreasing extraneous cognitive load. This means the learners did not necessarily need to use the offloaded information, and the learners effectively integrated and coordinated long-term memory and external information within the internal cognitive process to resolve a complex connected problem space.

In the context of complex learning, the combined use of supporting information-offloading and emphasis manipulation sequencing had a more positive impact on learning transfer compared to emphasis manipulation sequencing alone. Previous studies (Sweller, 2020; Sweller et al., 2019) found that although complex learning causes a high degree of cognitive load, learning transfer is improved if the learner experiences an optimal cognitive process (van Merriënboer & Kirschner, 2017). This means that sequencing with offloading could be used as a tool to aid learners in mastering supporting information and performing conventional tasks by adjusting and modifying the skills that they must learn, as well as the high levels of interactions among the constituent skills. Put differently, while learners may not have achieved complete mastery of supporting information within a specific learning period in a focused sequence, they were able to partially integrate and coordinate various aspects of supporting information by utilizing resources they constructed in the external environment while engaging in repetitive conventional tasks. As shown in Risko and Dunn (2015), a learner can obtain additional working memory capacity by allocating necessary cognitive processes to the outside environment, actively processing information, and more effectively integrating the processed information. Then, by constructing an efficient cognitive process, learners can perform the given task more effectively. Consequently, supporting information-offloading with emphasis manipulation sequencing can integrate constituent interactions that result from the cognitive processing of information to control the cognitive process more effectively, and could improve elaboration on the knowledge that is being taught.

Recommendations

The study offers theoretical and practical recommendations. The theoretical recommendation is that a combination of offloading and emphasis manipulation sequencing, known as whole task sequencing, is more effective in controlling cognitive loading compared to using emphasis manipulation sequencing alone. Effective management is crucial to ensure that the cognitive load does not exceed the learner's capacity, especially in complex learning situations. By offloading cognitive load and utilizing constituent skills and their interactions retrieved from working memory during task performance, learners can achieve more effective integration and coordination of knowledge. Additionally, our results underscore that while emphasis manipulation sequencing focuses on specific constituent skill sets for task performance, the backward progression of these skills may have lower immediate utility compared to the forward progression. However, by repeatedly connecting task intentions with cognitive cues provided through offloading, learners can elaborate on previous constituent skills in working memory, leading to the formation of a unified and systematized cognitive structure. These recommendations highlight the importance of combining offloading and emphasis manipulation sequencing for effective cognitive load management and knowledge integration during complex learning tasks.

The practical recommendations of this study are as follows. First, when learners encounter real-life problems, they perceive the difficulty to be lower compared to other tasks if they have access to cognitive cues that can aid in problem-solving. Therefore, instructors should allow learners to use the necessary information for problem-solving. However, it is important to note that information provided by the instructor, as well as information that learners have previously processed, can be perceived as unnecessary and increase extraneous cognitive load. To prevent this, learners should be empowered to utilize challenging information retrieved from available cognitive cues themselves. Second, offloading methods can holistically support more complex learning (e.g., Chen et al., 2023). In other words, offloading can reduce the cognitive load of complex strategies and concepts, allowing a learning process that requires higher elemental interactions. Thus, researchers can apply offloading methods to provide complex learning that consists of multiple aspects, and can develop methods for sequencing of complex learning that integrate aspects.

Limitations

This study is subject to certain limitations. First, the measurement of cognitive load was conducted only after the final task class in the sequence. This limited our ability to track the integration and coordination of offloaded information throughout the task sequencing, which is essential for understanding the effects of offloading. In future studies, we aim to measure cognitive loads at the end of each task class to observe the progressive effects of offloading as the sequence unfolds. Exploring alternative approaches to reducing cognitive load compared to learning transfer will also be valuable in the future. Second, real-life tasks can be categorized into circular, non-circular, and combined circular and non-circular tasks. Each task type requires different cognitive cues to be offloaded. Thus, future studies should focus on identifying the most optimal offloading tools for each task type and examining their effectiveness. By doing so, we can enhance our understanding of how offloading can be tailored to different task contexts. Addressing these limitations will contribute to a more comprehensive understanding of offloading, cognitive load, and their impact on learning outcomes. It will also provide insights into the development of effective offloading strategies for different types of real-life tasks. Third, the present study involved the offloading of supportive information for online learning tasks. In offline learning, cognitive cue generation through offloading and learning through supportive information should occur simultaneously. Offloading may actually hinder the integration and coordination of knowledge, skills, and attitudes acquired during the learning process. Future research should determine if the same results can be achieved offline as in an online learning context.

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Authorship Contribution Statement

Choi: Conceptualization, design, analysis, writing. Song: Writing, Editing/reviewing, supervision, final approval.

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