Form, Function, and Style in Instructional Design:

Emerging Research and Opportunities

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Chapter 1

Cognitive Load Theory, Spacing Effect, and Working Memory Resources Depletion:

Implications for Instructional Design

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ABSTRACT

In classroom, student learning is affected by multiple factors that influence information processing. Working memory with its limited capacity and duration plays a key role in learner ability to process information and, therefore, is critical for student performance. Cognitive load theory, based on human cognitive architecture, focuses on the instructional implications of relations between working memory and learner knowledge base in long-term memory. The ultimate goal of this theory is to generate effective instructional methods that allow managing students' working memory load to optimize their learning, indicating the relations between the form of instructional design and the function of instructional design. This chapter considers recent additions to the theory based on working memory resources depletion that occurs after exerting significant cognitive effort and reverses after a rest period. The discussed implications for instructional design include optimal sequencing of learning and assessment tasks using spaced and massed practice tasks, immediate and delayed tests.

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INTRODUCTION

Cognitive Load Theory (CLT) is an instructional theory that explains the effects of information processing load imposed by learning tasks on learners' cognitive system (Sweller, Merriënboer & Paas, 2019). The general goal of cognitive load theory is to generate innovative and effective instructional procedures to reduce learners' working memory load and optimize their information processing ability.

Working memory resources are limited due to its limited capacity, and this characteristic of working memory is central to the main topic of this chapter - the depletion effect. The next section provides a brief review of human cognitive architecture, its characteristics, and operation principles. Working memory and long-term memory are two major components of this architecture. In accordance with human cognitive architecture, the following section introduces the function of instructional design from the perspective of element interactivity and types of cognitive load. As the function of instructional design within the framework of cognitive load theory is to manage cognitive load, some load-reduction instructional methods are presented to address the form of instructional design and its relation with its function. Then, the working memory resources depletion effect is introduced, followed by the spaced practice design and the immediate vs. delayed tests as forms of evidence for the depletion effect. The chapter concludes with educational implications of working memory resources depletion effect for instructional design principles, including optimal sequencing of learning and assessment tasks using spaced and massed practice tasks, immediate and delayed tests.

HUMAN COGNITIVE ARCHITECTURE

Human cognitive architecture is considered as a natural information-processing system that operates based on a set of principles that determine the interaction between the external environment, working memory and long-term memory. These principles might be common to all natural information-processing systems such as human cognition or biological evolution by natural selection (Sweller & Sweller, 2006). The aspects of human cognitive architecture that are relevant to instructional issues can be summarized by five principles.

- **Information Store Principle:** All the natural information-processing systems have large stores of information that govern their behavior within the environment. For example, for biological systems, the information store is their genome (generic code store); for human cognitive architecture - it is the long-term memory's knowledge base. To perform well in a complex environment, human cognition must rely on a large amount of domain-specific knowledge (Chi, Glaser, Rees, & Steinberg, 1982) stored in long-term memory in the form of schemas (Tricot & Sweller, 2014). The goal of instruction is to increase the amount of domain-specific knowledge held in long-term memory.

- **Borrowing and Reorganizing Principle:** Most of the information in the store is borrowed from other sources and reorganized rather than just copied. The efficient way to acquire a large amount of domain-specific knowledge is to borrow information from others, such as imitating them (Bandura, 1986), listening to what they say and reading what they write. Before storing borrowed information, it usually is actively restructured, reorganized, and integrated with already available knowledge in long-term memory.
- **Randomness as Genesis Principle:** Although most information is borrowed from others, information can be initially constructed by a random generation and testing process during search-based problem solving. When the solution of a problem is not available for borrowing, possible moves are generated by random search for information or solution moves and tested for their effectiveness, with successful ones retained and unsuccessful ones discarded. This mechanism usually involves general problem-solving methods such as trial-and-error or means-ends analysis - the methods humans use in unfamiliar situations. In biological systems, this principle is realized in random mutations that could be adopted by the test of survival.
- **Narrow Limits of Change Principle:** When a natural information-processing system operates in a new environment (i.e., in the absence of information in the store that could guide its behavior in this environment), it requires a mechanism that could prevent significant random changes in its information store that might potentially damage the system. For example, in the biological evolution system, random mutations usually cause only small changes in the genome at a time. In human cognitive architecture, to prevent rapid, significant and therefore damaging changes to the knowledge base in long-term memory, the information system has to ensure that only a small amount of novel information is processed at a given time. Working memory, which has a limited processing capacity when dealing with novel information (Miller, 1956) and limited duration time (Peterson & Peterson, 1959), provides that assurance.
- Too many elements of information that are processed in working memory at the same time may exceed its capacity and cause cognitive overload. According to classical study by Miller (1956), humans cannot temporary store more than approximately seven elements of information simultaneously in short-term memory. This processing limitation of our cognitive system is a

major factor that influences the effectiveness of instruction from a cognitive load perspective. This potential working memory (or cognitive) overload happens when consciously processing a cognitive task at a specific (current) moment. It is not identical to the information overload in general, when we need to handle huge amounts of information over long periods of time. Cognitive load phenomena are associated only with conscious information processing on a scale of working memory operation, i.e., from around several to tens of seconds.

- **Environmental Organizing and Linking Principle:** When a natural information-processing system operates in a familiar environment (i.e., in the presence of information in the store that could guide its behavior), the narrow limits of change are lifted. In human cognition this means that the limited capacity of working memory only applies to processing novel information. For well-organized information held in long-term memory, there are no known limits for working memory capacity (Ericsson & Kintsch, 1995). Following appropriate stimuli from the external environment, working memory can process a huge amount of information retrieved from long-term memory to give a proper response to the external environment. If available knowledge structures (schemas) in long-term memory are used to encapsulate many information elements into larger chunks, these information-rich chunks are processed in working memory as single units, thus effectively increasing its actual capacity.

In human cognition, working memory is critical for constructing mental representations, however, it is limited in capacity and duration when dealing with unfamiliar information (Baddeley, 1986; Cowan, 2001; Miller, 1956). Accordingly, presenting a large amount of novel information to students may impose a heavy working memory load. In this situation, if the instructional design is suboptimal and imposes an additional cognitive load, working memory will be overloaded by breaking the Narrow Limits of Change Principle. Therefore, when learning materials consist of large amounts of novel information, carefully selecting instructional procedures to reduce cognitive load is critical. Still, working memory limitations do not apply to any well-organized information that has been learnt previously.

ELEMENT INTERACTIVITY AND TYPES OF COGNITIVE LOAD

Cognitive load generally refers to the load that performing a specific task imposes on our cognitive system (Sweller, Van Merrienboer, & Paas, 1998, 2019). Two dimensions have been used to consider the load: mental load (task-based dimension) and mental effort (learner-based dimension). The mental load relates to the load that is imposed by the demands from tasks, while the mental effort indicates the load that learners actually use to accommodate the demands of the task (Paas, Van Merriënboer, & Adam, 1994).

There are three types of cognitive load that have been traditionally discussed within the framework of cognitive load theory: intrinsic load, extraneous load and germane load (Paas, Renkl, & Sweller, 2003, 2004; Sweller et al., 1998, 2019; Van Merrienboer & Sweller, 2005). In this section, the three types of cognitive load will be described by using the concept of element interactivity which is the central concept in cognitive load theory.

Element Interactivity

Element interactivity is an index used to evaluate the difficulty of learning material (Chen, Kalyuga, & Sweller, 2015). An element can be a concept, a mathematical symbol or anything that can be learned. For example, to solve $x + 5 = 6$, for x, the five elements (x, +, 5, =, 6) that are interconnected and have to be processed simultaneously rather than individually in working memory to successfully understand the equation. These five interconnected elements, processed simultaneously in working memory, may indicate a high level of element interactivity. If instead, a non-English speaking student is asked to memorize English letters, such as A, B, C, then the level of element interactivity is low. As the student could memorize the letters one by one, individually, there is only one element (A or B or C) that needs to be processed in working memory at one time, and that element can be processed without referring to the other elements. For example, student could memorize A without referring to B and C. Therefore, this task indicates a low level of element interactivity.

Intrinsic Cognitive Load and Element Interactivity

Intrinsic cognitive load is imposed by learning material that needs to be processed in order to achieve the learning goal. This type of load depends on the nature of learning materials. As element interactivity is an index to show how difficult learning materials are, intrinsic load and element interactivity are interconnected. Let's use the same examples for element interactivity as those used above to explain the concept of intrinsic cognitive load. In order to solve $x + 5 = 6$ for x, the five elements (x, +, 5, =, 6) that are interconnected must be processed simultaneously in working memory for understanding the equation, which indicates high levels of element interactivity and accordingly, high levels of intrinsic cognitive load are required to achieve the learning goal. If a non-English speaking student is asked to memorize English letters, then the intrinsic load is low as this type of material is low in element interactivity.

As students' levels of prior knowledge (or levels of learner expertise) may influence the level of element interactivity (Chen, Kalyuga, & Sweller, 2016a, 2016b, 2017), learners' expertise should also be considered to determine the level of intrinsic load. While the above equation may consist of five interconnected elements for novices, it may contain only one element for experts, as their previously acquired schema for solving this type of equations can be processed as a single entity in working memory, which reduces the level of element interactivity, and so the level of intrinsic load. Therefore, working memory resources (limited by capacity of working memory) used to deal with intrinsic cognitive load that is determined by the learning goals of specific tasks directly contribute to students' learning, making this type of load productive and necessary for learning.

Extraneous Cognitive Load and Element Interactivity

Extraneous cognitive load happens when the instructional design is suboptimal. Namely, this type of load is imposed because, due to an ineffective instructional design, learners are involved in activities that are irrelevant to achieving learning goals. Therefore, the extraneous load can be altered by modifying instructional procedures and techniques.

Element interactivity also can be used for explaining extraneous cognitive load. Interconnected elements that are only derived from a task (defined by the corresponding instructional goal) cause intrinsic load, whereas elements that interact solely due to the way the instruction is designed (corresponding learning activities are selected or presented to learners) determine extraneous cognitive load (Sweller, 2010). For example, consider selecting problem solving activities to achieve the goal of learning a solution procedure (schema) for a specific type of problems, and asking learners to generate solutions by themselves (Cooper & Sweller, 1987). In the absence of relevant knowledge of solution procedures, the learners would inevitably use search-based problem-solving strategies, such as means-ends analysis. The means-ends analysis requires simultaneous handling of many element of information – initial problem state, its final state (goal), the chain of sub-goals that reduce the distance between the initial and final states, the operations that would allow transitioning between the intermediate states. Such a large number of interactive elements generated during search-based problem solving may cause a high level of cognitive load. This type of cognitive load is an extraneous cognitive load, as it is caused by instructional design, in this case, by selecting problem-solving tasks for achieving the instructional goals.

As the extraneous cognitive load is imposed by the way learning materials are selected and presented, using limited working memory resources to deal with this type of cognitive load does not contribute to students' learning. Therefore, reducing or eliminating extraneous cognitive load to free more working memory resources for dealing with intrinsic load is necessary.

Germane Cognitive Load

Even though germane cognitive load has been often considered as a separate type of productive cognitive load that directly contributes to schema acquisition and automation, in more recent versions of cognitive load theory, it is closely associated with the intrinsic cognitive load (Sweller, 2010). The three-component model of cognitive load has been recently challenged as intrinsic load and germane load are very close and difficult to clearly differentiate. Therefore, a dual model of cognitive load has been suggested that includes only intrinsic and extraneous types of cognitive load (Kalyuga, 2011). With this approach, germane cognitive load (or germane resources) is regarded as the amount of working memory resources that are actually allocated to dealing with the element interactivity associated with intrinsic cognitive load (Sweller et al., 2011). Thus, it represents a dimension of actually allocated working memory resources which is different from the dimension of cognitive load as the amount of working memory resources required by a task. The actually allocated working memory resources are influenced by factors beyond those related to purely instructional design decisions, such as learner motivation, engagement, and affect. This dimension is essential for making connection between cognitive load theory and motivational theories of learning, which represents one of the important issues to deal in future research in this field.

Total Amount of Cognitive Load

Based on the dual model of cognitive load in recent descriptions of cognitive load theory (Kalyuga, 2011; Sweller, 2010; Sweller et al., 2011), the two independent types of cognitive load - intrinsic and extraneous - are additive, and the total load formed by intrinsic and extraneous loads indicates the required working memory resources. If the total required load exceeds the available capacity of working memory, learning will be inhibited. As the capacity of working memory is traditionally regarded as constant for a given learner (relevant to her/his domain specific knowledge structures), if most of this capacity is used for dealing with extraneous, irrelevant load, fewer resources will be available for dealing with essential, intrinsic load.

Accordingly, instructional design should eliminate (ideally) or reduce extraneous load, as this kind of load has nothing to do with achieving specific learning goals.

As for intrinsic load, it should be managed by selecting appropriate learning tasks (Kalyuga, 2011). The learning task should not be too complex in order not to impose an extremely high intrinsic load and make working memory break down, however, it should not be too simple in order to be sufficiently cognitively challenging and motivating (Schnotz & Kürschner, 2007). The resources of working memory that are actually allocated to dealing with intrinsic load which is relevant to learning and schema acquisition (germane resources) need to be maximized, while resources allocated to dealing with extraneous load should be reduced.

LOAD-REDUCTION INSTRUCTIONAL DESIGNS

As extraneous load is irrelevant to learning, the main function of generating innovative and effective instructions, within the framework of cognitive load theory, is to reduce extraneous load imposed on working memory. There are different types of load-reduction instructional design methods. In this section, some classic load-reduction instructional designs (*Form*) are introduced to give readers specific illustrations of how cognitive load is managed (*Function*).

Worked Example Effect

Using worked examples could be traced back to the mid-1950s. The paradigm used in those studies was learning by examples. The example-based learning had initially aimed at the acquisition of simple concepts, then it was used to investigate learning of more complex forms of knowledge (Atkinson, Derry, Renkl, & Wortham, 2000).

A worked example includes the problem statement with associate procedures (Atkinson et al., 2000). The first example-based research conducted within the framework of cognitive load theory applied the idea of worked example-problem solving pairs (Sweller & Cooper, 1985; Cooper & Sweller, 1987), namely, students were presented with a worked example to study first, followed by solving a similar problem. This paradigm has been proved to be superior to engaging students in solving problems only, indicating the worked example effect.

The worked example effect could be directly explained by human cognitive architecture. When students are presented worked examples, the relevant knowledge structures could be borrowed (borrowing and re-organizing principle) compared to solving problems which requires random generation of solutions (producing more interactive elements which may break the narrow limit of change principle). Many research studies have found the effectiveness of using worked examples in algebra (Sweller & Cooper, 1985), statistics (Paas, 1992), geometry (Paas & Van Merriënboer, 1994; Schwonke, Renkl, Krieg, Wittwer, Aleven & Salden, 2009), physics (Reisslein, Atkinson, Seeling & Reisslein, 2006; Van Gog, Kester & Paas, 2011; Van Gog, Paas & Van Merriënboer, 2006) and other domains.

Although using worked example-problem solving pairs is superior to engaging problem solving only, the design of worked examples is critical (Catrambone, 1994; Catrambone & Holyoak, 1990; Mwangi & Sweller, 1998; Ward & Sweller, 1990; Zhu & Simon, 1987). If the internal structure of worked examples is not properly designed, the effectiveness of using worked examples may disappear due to imposing higher levels of extraneous load. The following sections describe some of such situations and appropriate designs to prevent them.

Split Attention Effect

Split attention effect stipulates that separated related sources of information must be physically integrated for students to mentally integrate them without causing high levels of extraneous load. There are two types of split sources of information: spatially and temporally separated (Sweller et al., 2011).

Spatially Separated Sources of Information

Learning geometry may frequently involve dealing with spatially separated sources of information. When students are presented a geometry example, the geometric shape and associated procedures are usually separated. In order to fully understand the material, students have to hold information from the geometric shape in working memory while searching for the relevant procedures. On the other hand, students may need to hold much of information about procedures in their working memory while searching back in the geometric shape for relevant visual components. In both cases, a heavy extraneous cognitive load could be imposed on working memory and interfere with learning. Therefore, if the two separated sources of information, a geometric shape and procedures, are physically integrated beforehand, then students do not need to search between them, which reduces levels of extraneous load. The cases of spatially separated sources of information causing split attention have been found in many research studies (e.g., Chandler & Sweller, 1992; Ayres & Youssef, 2008; Rose & Wolfe, 2000; Lee & Kalyuga, 2011).

Temporally Separated Sources of Information

This type of split-source design formats includes related sources of information that are separated in time rather than by the location. Baggett (1984) and Mayer and Anderson (1991, 1992) investigated this issue by comparing two versions of instructional design: visual and auditory sources of information were presented simultaneously or auditory information was presented before or after the relevant visual information. The results favored presenting the visual and auditory information in concurrent form rather than in the temporally separated form.

Split attention situations occur when they involve multiple sources of information that are mutually dependent and not just re-describe each other. If the multiple sources of information re-describe each other in different formats, their integration for learning may cause another structural design issue for worked examples.

The Redundancy Effect

Similar to the split attention effect, the redundancy effect also deals with multiple sources of information. However, in this case, the multiple sources of information re-describe each other, namely, a single source of information could be fully understood without referring to other sources of information. Within the framework of Cognitive Load Theory, any information that is not necessary and is irrelevant to learning should be regarded as redundant (Sweller et al., 2011).

Chandler and Sweller (1991) conducted the first study within the framework of cognitive load theory showing a redundancy effect. One group was presented with integrated text and a diagram that essentially re-described the textual information, while another group studies from the separated text and the diagram. Results favored the second group in which learners were able to ignore the redundant source of information, indicating a redundancy effect. Following this experiment, other research studies have also found the redundancy effect in other domains (Sweller & Chandler, 1994; Chandler & Sweller, 1996; Mayer, Heiser & Lonn, 2001; Kalyuga, Chandler & Sweller, 2004).

The redundancy effect may be counterintuitive (Sweller et al., 1998), as many people feel that learning the same information repeatedly in different formats should be beneficial for learning. However, the available empirical evidence tells us another story: presenting redundant information together with essential information may impose a heavy extraneous load on working memory. The learners may not be able to ignore the redundant information, especially in the integrated format, and processing redundant information may unnecessarily require allocating extra working memory resources.

Variability Effect

Unlike the above effects, the variability effect aims to maximize the level of intrinsic load in order to enhance the transfer of learning. Within the framework of cognitive load theory, variability effect is implemented by using examples that vary their context (Clark, Nguyen & Sweller, 2006). Learners who are presented with varied-context examples are assumed to be better able to distinguish the relevant and irrelevant features of worked examples (Van Merriënboer & Sweller, 2005), thus forming conditionalized schemas (Clark et al., 2006).

Paas and Van Merriënboer (1994) conducted the first experiment investigating the variability effect within the framework of Cognitive Load Theory by applying Pythagoras' theorem to calculate the distance between two points. The experiment compared low-varied worked examples which only changed the values of the problem variables with high-varied worked examples which changed both the values and the structure of the problem. The post-test transfer performance favored the group using high-varied worked examples, supporting the hypothesis of variability effect.

Variability effect was also found with examples that varied the levels of contextual interference. Low levels of contextual interference relate to a series of problems that could be solved by using the same set of skills, whereas, high levels of contextual interference relate to a series of problems that requires different sets of skills but are placed next to each other (Sweller et al., 2011). Assuming A, B, C are three different skills, then the sequence of A-A-A, B-B-B or C-C-C targets a low level of contextual interference, compared to the sequence of C-B-A, B-A-C, B-C-A for a high level of contextual interference (Van Merriënboer, Schuurman, De Croock & Paas, 2002). De Croock, van Merriënboer, and Paas (1998) found that using task sequences with high levels of context interference caused higher levels of mental effort and increased learning time, but resulted in fewer errors on the posttest transfer test, compared to the ask sequences with low levels of contextual interference.

The above instructional designs aim to reduce the extraneous load which is irrelevant to learning but to maximize the intrinsic load which is relevant to learning. However, the idea of managing cognitive load is based on the assumption that working memory resources of a learner available for dealing with a specific task are relatively constant, which has been challenged recently (Chen, Castro-Alonso, Paas, & Sweller, 2018).

WOKING MEMORY RESOURCE DEPLETION

Depletion Phenomena

Depletion phenomena happen when two tasks must be processed in immediate sequence, leading to worse performance on the second task because of working memory capacity reduction following the first task. For example, Persson, Welsh, Jonides, and Reuter-Lorenz (2007) indicated that when dealing with higher cognitive processes, resources might be temporarily depleted. Persson et al. (2007) applied a within-subject experimental design to investigate the depletion effect. In their experiment, participants were required to do verbal generation task based on the presented nouns. Participants were placed in low and high interference conditions. For the low interference condition, possible associate responses to the nouns were limited (e.g., SCISSORS—CUT), while for the high interference condition, the nouns allowed several obvious suitable response options (e.g., BALL—THROW, KICK, BOUNCE). Participants were fatigued with three distinct interference resolution processes for 18 minutes, followed by a test including tasks that required different interference resolution mechanisms. The results indicated that the test performance was affected only when test items required the same resources that were initially depleted, with no performance depression on test items using different cognitive resources.

Anguera et al., (2012) followed the depletion approach of Persson et al. (2007). They had designed visuomotor tasks to selectively fatigue spatial working memory, then evaluated the participants' performance on tasks that were related or unrelated to the corresponding cognitive processes. Results indicated that the depletion of working memory resources negatively influenced the rate of early visuomotor adaptation. Also, intentionally training working memory capacity could not improve the rate of visuomotor adaptation.

The depletion effect has also been discussed in connection with self-control which happens when a person tries to change the way he or she would think, feel or behave (Muraven & Baumeister, 2000). Muraven, Tice and Baumeister (1998) found that when performing two consecutive acts of self-control, the performance on the second act could be depressed. The impaired performance happened even when two different acts of self-control were involved. The provided explanation suggested that varied types of self-control consumed the same resource (or self-control strength) which is very limited and therefore could be depleted quickly. This self-regulatory depletion mode has been tested with different types of tasks (Baumeister, Bratslavsky, Muraven, & Tice, 1998; DeWall, Baumeister, Stillman, & Gailliot, 2007; Muraven et al., 1998; Schmeichel, Vohs, & Baumeister, 2003).

Schmeichel et al. (2003) assigned participants into self-regulation and non-regulation groups. In the self-regulation group, participants were required to regulate emotion or attention initially, while participants in the non-regulation group were not required to do those exercises. The results showed that depletion was found with the tasks requiring complex thinking, such as logical and reasoning tasks (Study 1), cognitive extrapolation tasks (Study 2), and a test of thoughtful reading comprehension (Study 3), but no evidence of depletion was found for memory and recall tests. In their Experiment 1, Muraven, Shmueli and Burkley (2006) used two tasks that required solving moderately difficult multiplication problems (math problem condition) and suppressing the thought of a white bear (thought suppression condition). In the thought suppression condition, learners were required to write down their thoughts but without thinking about the white bear (Wegner, Schneider, Carter, & White, 1987). It was assumed that only thought suppression condition would deplete the resources compared to working on arithmetic problems that was automatic. In Experiment 2, participants were required to type a paragraph either with letter e or without it. The condition involving typing without e required high levels of self-control. The tasks were then changed to trying cookies and celery in Experiment 3. All experiments indicated that participants using self-regulation depleted resources and performed worse in an intervening test of self-control compared to participants without resource depletion.

Constant Working Memory Resource Assumption

Based on a dual model of cognitive load (Kalyuga, 2011), two independent types of cognitive load, intrinsic and extraneous cognitive load, are additive. The Narrow Limits of Change Principle assumes that the working memory resource of a specific individual available for dealing with a specific task is relatively constant (Chen et al., 2018). Therefore, this assumption may provide a baseline for discussing relations between intrinsic and extraneous types of cognitive load. Specifically, if the total amount of intrinsic and extraneous cognitive load exceeds the assumed constant working memory capacity, learning will be restricted. To optimize students' learning, instructions should be designed to minimize extraneous cognitive load which is irrelevant to achieving specific learning goals, to accordingly increase the relative amount of working memory resources left to deal with the intrinsic cognitive load.

However, the assumption of a constant working memory resource in cognitive load theory may have been challenged recently (Chen et al., 2018). In cognitive load theory, the traditional and only factor influencing working memory capacity is the content of long-term memory - the organized knowledge structures (schemas) related to the task at hand. Based on human cognitive architecture, working memory has limited capacity when processing novel information for which there is no related knowledge in learner long-term memory, with no known limits for well-organized information held in long-term memory via Environmental Organizing and Linking Principle. Namely, the more schemas that are relevant to the task are stored in long-term memory, the fewer working memory resource may be consumed. Therefore, the working memory resource is assumed to be alterable by the content of long-term memory only. However, it has been indicated that intensive cognitive effort may deplete working memory resources due to a working memory capacity reduction after heavy cognitive processing (Chen et al., 2018), suggesting that long-term memory may not be the only factor affecting the characteristics of working memory.

Working Memory Resources Depletion Effect and Cognitive Load Theory

The working memory resources depletion could be discussed within the framework of cognitive load theory. Particularly, working memory resources deplete when the two sequential tasks have similar cognitive elements, and the reduced working memory capacity depresses the performance on the second task due to increased cognitive load. However, research indicates that after some rest, the resources available for the second task could be restored (Tyler & Burns, 2008), resulting in reduced cognitive load.

There is little empirical research investigating the effect of cognitive effort on resource depletion directly. Experiments conducted by Schmeichel (2007) provide some empirical evidence. In the first experiment, participants who were required to ignore irrelevant words of a person speaking with no copy of the narrated text on the screen, depleted their working memory resources, compared to others without this requirement. Similarly, students who were asked to write a story without using the letters *a* or *n* performed worse on a working memory capacity test than the students without this restriction in the second experiment. In the last experiment, a group of participants was required to exaggerate their emotions when watching a movie compared to another cohort who watched movie normally. The cohort watching the movie normally depleted fewer working memory resources than those who had to put much effort in exaggerating their emotions.

Schmeichel et al. (2003) found similar results to those obtained by Schmeichel (2007). Even though the working memory capacity was not measured in their study, they used reasoning, problem solving, or reading comprehension tasks as measures of the resulting performance. The results indicated again that with resource depletion, the learner performance on reasoning, problem solving or reading tasks became depressed.

Compared to Schmeichel's et al. (2003) results on general depletion effects, Healey, Hasher, and Danilova (2011) provided empirical evidence of some specific working memory depletion effects. They varied stimuli that were to be ignored in the first task, but had to be remembered afterwards. The multiple experiments showed that ignoring words in the initial task depressed the performance on the following working memory test that was words-based (Experiment 1), but not on the test that was arrows-based (Experiment 2). Similarly, the performance on arrow-based working memory test was impaired if ignoring arrows was required in the first task (Experiment 3), but no depression on working memory test that was words-based was observed (Experiment 4). Therefore, the working memory resource depletion may happen when there are similarities between to-be-ignored stimuli in the beginning and to-be-remembered stimuli on the following working memory test. However, none of those experiments used educationally-relevant materials. Schmeichel et al. (2003) also observed general depletion effects by using self-control tasks and found that depletion might not be applicable to simple tasks. For example, the resource depletion effect was not found with nonsense syllable memorization task (Schmeichel et al., 2003).

Overall, the previous research has not studied the resource depletion effect with realistic learning tasks but rather, investigated general cognitive processing with typical experimental psychology tasks. However, the spacing effect discussed in the next section may be used as a means for investigating resource depletion in learning-relevant environments.

RESOURCE DEPLETION: EVIDENCE FROM SPACED PRACTICE DESIGN

The spacing effect demonstrates that studying learning materials presented with time spaces between learning tasks is superior to studying all the content presented under massed conditions. This effect, which is also called the massed vs. spaced effect, has been well-documented in learning research (Gluckman, Vlach, & Sandhofer, 2014; Kapler, Weston, & Wiseheart, 2015).

To test the working memory resource depletion effect, a spaced practice design was used by Chen et al. (2018). Two experiments tested two hypotheses about possible explanations of the spacing effect: 1) the spacing effect is caused by working memory resource depletion following a massed practice; 2) a lower content test score and more working memory resource depletion would be found after the massed practice. The first experiment used a quasi-experimental design. Participants in one class were allocated to the massed practice condition with another class allocated to the spaced condition. Three pairs of worked example-problem solving tasks were designed to teach Year 4 students how to calculate fraction addition, where two fractions had different denominators. In the massed condition, students received the three pairs at one time, whereas in the spaced condition, each of the three pairs was taught on three separate consecutive days. All the three pairs were presented via a projection on the screen. Each slide was set a fixed time for presentation, with the total learning time equal for both conditions. The massed condition involved a working memory capacity test directly after learning the last pair, while in the spaced condition, the same test was conducted on the fourth day. The working memory test was also presented on the screen with the same projector, but students were required to give answers on the provided answer sheet.

The test items for the working memory test were a set of equations, such as $5 + 6 + 2 = 13$. Students were required to judge whether the equation was correct. If the equation was correct, they chose smiling face, if not, they chose sad face on the answer sheet. Also, students were instructed to remember the first digits of the equations, such as 5 for $5 + 6 + 2 = 13$, and then recall them in the same order on the answer sheet. However, they were not allowed to record the to-be–remembered first digits and to choose the smiling or sad faces anywhere on the answer sheet during the presentation of the whole set of equations. They could only record their answers when they were instructed to do so. Therefore, during the presentation of the whole set of equations, participants had to process and store information in their working memory. There were multiple levels of test items designed for the working memory capacity test to increase the difficulty of the test. For different levels, there were different numbers of test items: the higher the level, the more test items it involved. For example, for Level 2, there were two items (namely, only judging two equations and memorizing two digits), while for Level 3, there were three test items etc. Participants in both conditions also completed a content-based test after the working memory capacity test. The results confirmed the hypotheses: the spaced condition was superior to the massed condition on the content test and indicated a higher working memory capacity compared to the massed condition.

The second experiment used the same procedures and materials, but a counterbalanced design was applied. In Week 1, one class was assigned to the massed condition, and another class was allocated to the spaced condition. In Week 2, while using different learning materials, the class of the massed condition in Week 1 was allocated to the spaced condition with the class of the spaced condition in Week 1 was allocated to the massed condition. The results of Experiment 1 were replicated in Experiment 2 – again, the spaced condition was superior to the massed condition on the content test and indicated a higher working memory capacity.

The results of these two experiments may have some important theoretical and practical implications. Concerning the theoretical implications, the two experiments may have set up a new perspective of cognitive load theory with working memory resources depletion phenomena following the significant cognitive effort. Also, the two experiments demonstrated the spacing effect, and may have provided another explanation for this effect. Namely, the spacing effect may be caused by working memory resource depletion after massed practice rather than distributed study-phase retrieval only (Delaney, Verkoeijen, & Spirgel, 2010). Regarding practical implications, working memory resources depletion and potentially increased cognitive load need to be taken into consideration when sequencing tasks that may require significant cognitive effort. For example, using the spaced design may be more suitable for students compared to the massed presentation, as more working memory resource can be used for learning using the spaced design.

RESOURCE DEPLETION: EVIDENCE FROM IMMEDIATE VS. DELAYED TESTING DESIGNS

In the conceptual design of spaced practice, time is used as a factor that influences working memory resources depletion and restoration. Spreading the tests across different time periods, such as using immediate vs. delayed tests, might also have the same effect.

Previously published evidence has demonstrated that students can show higher scores on delayed testing as compared to immediate assessments (e.g., Roediger & Karpicke, 2006; Rohrer & Taylor, 2007; Soderstrom & Bjork, 2015). A potential explanation for these findings, consistent with cognitive load theory, is that working memory resources can be depleted and later replenished (see Chen et al., 2018). The working memory resources depletion effect implies that a delayed test can be superior to an immediate test because delayed assessments allow time for working memory resources to replenish from previous processing, while immediate testing adds cognitive load to working memory that has already been depleted by the preceding learning activities (Chen, Yeo, & Kalyuga, submitted). In Chen et al.'s (submitted) experiment, 23 Year 2 primary school students were presented with four worked examples for learning about the subtraction of two unlike fractions. After a learning phase, a working memory resources test was conducted to all students. The test was the same as the one used for testing spaced practice design described in the previous section. An immediate test for subtraction of two unlike fractions was administered on the first day of experiment. On the second day, all students came back to do a delayed post-test with the same testing content (there was no feedback given after the immediate test). Results showed higher scores on the delayed test due to more working memory resources depleted for the immediate test. This phenomenon has clear implications for the design of learning materials involving learner assessment, especially diagnostic (summative) testing: when dealing with cognitively effortful materials, the assessment tasks should better be delayed rather than administered immediately after the learning tasks.

FUTURE RESEARCH DIRECTIONS

The working memory resources depletion effect within the framework of cognitive load theory has opened a new direction for future research. Based on the results of Chen et al. (2018), working memory resources tests may be used in investigating other cognitive load effects, such as the worked example effect. One of the factors contributing to the superiority of using worked examples compared to problem solving tasks might be causing less working memory resources depleted. Also, all cognitive load effects have been investigated from the perspective of working memory load only, however, learner motivation and emotional states may also affect the allocation of working memory resources (Chen, Castro-Alonso, Paas & Sweller, 2018). Therefore, in future research, these factors need to be integrated into conceptual framework of cognitive load theory.

Similar to spacing effect, the working memory resources depletion may be used to explain the interleaving effect by comparing a blocked design with an interleaved design. Once the empirical evidence is obtained using measures of learner working memory capacity, specific instructional recommendations could be provided for school teachers on sequencing learning tasks and practice exercises.

CONCLUSION

Cognitive load theory, based on contemporary knowledge of human cognitive architecture, aims to generate innovative and effective instructional techniques (*Form*) to optimize students' learning by managing learner working memory load (*Function*). Traditionally, cognitive load theory assumes a constant amount working memory resources for a given learner and the task. However, the results from spaced practice experiments may have challenged this assumption, indicating that working memory resources may be depleted after heavy cognitive effort and be restored after a rest period. Therefore, the constant working memory resource assumption may need to be revised to extend cognitive load theory by incorporating the working memory resource depletion phenomenon. The obvious instructional implication of this phenomenon is the suggestion to manage the sequences of effortful tasks of a similar nature in a way that they do not follow each other immediately, but rather intermixed with other tasks and some breaks or rest time in-between. In particular, the spaced design of a series of tasks may be superior to their massed presentation for students' learning, as there could be more working memory resources depleted after massed practice compared to spaced design.

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KEY TERMS AND DEFINITIONS

Cognitive Load Theory: An instructional theory for generating effective instructional methods based on knowledge of human cognitive architecture.

Human Cognitive Architecture: The base of cognitive load theory, revealing the relations between working memory and long-term memory.

Long-Term Memory: Permanent storage of learned knowledge structures.

Redundancy Effect: An instructional effect indicating that for more efficient learning, any unnecessary information should be eliminated rather than included.

Spaced Practice Design (Spacing Effect): An effect indicating the superiority of studying learning materials presented with time spaces between learning tasks compared to studying learning materials presented without time spaces.

Split-Attention Effect: An instructional effect indicating that for more efficient learning, multiple separated sources of interdependent information must be physically integrated.

Worked Example Effect: An instructional effect indicating the superiority of using worked examples rather than problem solving tasks.

Working Memory: A cognitive system with a limited capacity that is responsible for temporarily holding and processing information.

Working Memory Resources Depletion: A depletion of working memory resources that happens after heavy cognitive processing.