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REVIEW ARTICLE

Four Ways of Considering Emotion in Cognitive Load Theory

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Abstract
We discuss four ways in which emotion may relate to cognitive load during learning. One perspective describes emotions as extraneous cognitive load, competing for the limited resources of working memory by requiring the processing of task-extra or task-irrelevant information. Another perspective shows that encoding, storage, and retrieval of information are affected by emotion even before awareness of the material, and that emotion may directly affect memory by broadening or narrowing cognitive resources, and by mechanisms such as mood-dependent and mood-congruent processing. A third perspective describes how emotion may affect intrinsic cognitive load, such as when emotion regulation is part of the learning outcomes. We also discuss a dual-channel assumption for emotions. A final perspective is that emotion affects motivation, and, in turn, mental effort investment. These four ways of considering emotion as part of CLT are best understood when taking an interval view of cognitive load.

Keywords Cognitive load theory · Processing models · Emotion · Emotion and learning · Emotion and cognitive load

Introduction

Cognitive Load Theory (CLT), conceived in the 1980s by John Sweller and colleagues (Sweller 1988; for a comprehensive review, see Sweller et al. 2011), has become one of the most important learning theories in educational psychology. CLT is also popular with practitioners as it allows for very useful and concrete predictions and prescriptions in instructional design. The theory's significance is in part due to the fact that it is grounded in an

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understanding of the human cognitive architecture that is supported by decades of research on working memory models (Baddeley 1986; Cowan 2001; Miyake and Shah 1999), schema construction (McVee et al. 2005; Paas et al. 2004), and mental effort (Salomon 1984). CLT is continuing to evolve by incorporating new theoretical and research insights from these and other areas (Plass et al. 2010).

In this paper, we highlight affective processing, and especially a learner's emotional experiences during learning, as one of the areas that has not yet been sufficiently considered in the context of CLT (Brünken et al. 2010). Based on recent research, we argue that a comprehensive understanding of cognitive processing requires the consideration of affective factors, factors related to the experience of feeling or emotion. This is grounded in recent findings from affective neuroscience, but also supported by developments in theories related to CLT: Cognitive Load Theory, which in its traditional form represents a capacity model of learning, is often accompanied by processing models such as the Cognitive Theory of Multimedia Learning (CTML, Mayer 2005, 2009). Recent advances of models on processing multimedia materials based on CTML have added affective components, and we believe that CLT should similarly begin to incorporate emotion.

In support of our argument to consider emotion in CLT, we first define Cognitive Load Theory and describe some recent refinements of CLT, with a special focus on the interval view of cognitive load advanced by Kalyuga and Singh (2016). We then describe how processing models of multimedia learning have incorporated affect, highlighting the inclusion of emotion, motivation, and meta-cognition by Moreno and Mayer (2007) and the inclusion of emotion as separate processing channel by Plass and Kaplan (2016). Next, we summarize research on emotion and cognition, as well as research on learning and emotion, including research on emotional design. We conclude by describing four ways in which emotion relates to cognitive load.

Cognitive Load Theory Defined

Cognitive load theory considers instructional implications of the human cognitive architecture, which includes two major components—working memory and long-term memory (see Sweller et al. 2011, for a recent overview of the theory). Working memory, in which we consciously process information and construct new knowledge, is very limited in capacity and duration when dealing with new information (Baddeley 1986; Cowan 2001). Long-term memory permanently stores knowledge structures (or schemas, the organized generic knowledge structures in specific domains) that guide our behavior. These knowledge structures also allow bypassing working memory limitations when dealing with familiar information by chunking many interconnected elements of information into a single unit which is treated as an element in working memory.

By definition, cognitive load is working memory load required from a learner for performing a cognitive task. The part of cognitive load that is directly relevant to learning is called intrinsic or productive load. According to cognitive load theory, this load needs to be managed to be within the available capacity of working memory. The part of cognitive load that is unnecessary for learning is called extraneous or unproductive load (see Kalyuga 2011; Mayer and Moreno 2003; Sweller 2010 for detailed discussions of these and other basic definitions). This load is caused by cognitive activities that are performed because of the specific design or selection of learning tasks. For example, one of the sources of extraneous cognitive load that have been traditionally considered by cognitive load theory is caused by search processes involved in unguided or minimally guided learning tasks when used for novice learners. It has been argued that in the absence of relevant prior knowledge and external instructional guidance, these learners would need to resort to using such default cognitive strategies as means-ends analysis or trial-and-error techniques, which usually impose significant working memory load (Sweller 1988). Explicit instruction in the form of worked examples has been demonstrated to reduce (if not eliminate) this load, thus enhancing acquisition of solution schemas. This is described as the *worked example effect*; see Sweller et al. (2011) for an overview.

According to cognitive load theory, during the initial phases of instruction, novice learners should always be provided with explicit instruction in targeted concepts and procedures rather than solving or exploring related problems independently (Sweller et al. 2007). In the absence of sufficient prior knowledge, any initial problem-solving attempts using search processes would cause high levels of extraneous cognitive load preventing meaningful learning of domain-specific solution schemas from such activities. In contrast to novice learners, for more knowledgeable students in the specific task area, cognitive load theory suggests using reduced or minimal guidance learning tasks. Such interactions between levels of learner prior knowledge (or expertise) and different levels of instructional guidance are instances of the *expertise reversal effect* (Kalyuga 2007; Sweller et al. 2011).

Recent Advances in Cognitive Load Theory Relevant to the Inclusion of Emotions

Contemporary CLT uses an evolutionary approach to support key features of human cognitive architecture by grounding human cognition within a broader class of natural information processing systems with common structural characteristics and operational principles (Sweller 2003, 2004; Sweller and Sweller 2006; Paas and Sweller 2012). In particular, a close analogy was postulated between the human cognitive system and biological evolution by natural selection, with main principles assumed to be common to all natural information processing systems. Yet, in contrast to other natural information processing systems, humans need to be actually motivated to acquire knowledge they usually learn in educational institutions. In other natural information processing systems, transmitting and receiving information patterns is the natural form of "learning" for which they are naturally "motivated." In human cognition, such natural learning could only be applied to the acquisition of the type of knowledge sometimes referred to as biologically primary knowledge (Geary 2007)—intuitive types of knowledge that humans evolved to acquire rapidly and implicitly by being involved in the corresponding types of environments (e.g., skills in speaking and listening basic native language).

However, this implicit knowledge is not the type of knowledge we usually learn in organized educational settings, such as scientific knowledge, writing, and reading skills. We have not evolved to implicitly acquire this knowledge and are not naturally motivated for it, and it is therefore called biologically secondary knowledge. Accordingly, in the process of learning such knowledge, learning activities might be required that are aimed at getting learners predisposed, motivated for, and engaged in learning as part of the goals of preparing for learning. The evolutionary perspective in cognitive load theory has generated productive ideas about the nature of human cognition and deep reasons behind successful instructional manipulations, including understanding of the importance of considering motivational and affective factors that influence human cognition and learning.

To operationalize cognitive load, the concept of element interactivity is used in cognitive load theory. It is defined as the level of interconnectedness between the information elements that need to be processed in working memory simultaneously to make sense of the learning tasks or materials (Sweller 1994, 2010). As with most theoretical concepts, it is a simplification that might not always describe all the complex interplay of various processes that are involved in performing a cognitive task and thus contribute to cognitive load. For example, all sorts of cognitive operations associated with executive functions (e.g., shifting attention, inhibiting processing of irrelevant information), inferring or abstracting information, and integrating different sources of information are also parts of working memory processes.

To capture this complexity theoretically, Kalyuga (2015) and Kalyuga and Singh (2016) suggested viewing cognitive load as the intensity (magnitude per unit, concentration) of cognitive processes involved in reaching a specific goal within an interval of time that is characteristic for the timescale of working memory operation. For simple tasks like recalling random sets of letters, the duration of short-term memory was estimated to be around 20 seconds (Peterson and Peterson 1959). For more complex tasks that involve not only storage but also manipulation of information, the duration of working memory would be even shorter as the attention would shift to new information faster. On the other side, the timescale of working memory operation also depends on the learner's knowledge base (or level of expertise) due to the long-term working memory phenomenon (Ericsson and Kintsch 1995), which is also related to the skilled memory effect (Ericsson and Staszewski 1989) and the knowledge encapsulation effect (Rikers et al. 2000). Therefore, the timescale could be significantly extended in the areas of knowledge or expertise. Viewing cognitive load as intensity of cognitive activity combines both characteristics of working memory: its limited capacity and its limited duration. If a specific goal is not achieved within the timescale of working memory operation due to high intensity (e.g., too many operations within the timescale), learning could be inhibited. An important theoretical implication of this view of cognitive load is that it becomes a local, micro-level characteristic of working memory operation associated with relatively short time intervals rather than a global, macro-level characteristic over longer periods of time. Accordingly, cognitive load is caused by processes that occur within the timescale of working memory operation and are directed towards a specific local goal, whether it is learning an equation solution step or getting engaged with a learning task. Learning over longer time periods happens in a sequence of local learning episodes that have a cumulative effect: a local learning episode affects learning during the subsequent local episodes. An excessively high intensity of cognitive processes (cognitive overload) during one such episode may disrupt learning during the following periods. Working memory processes on the local timescale depend on specific local-level goals of the task and the level of learner expertise.

It should be noted that this view of cognitive load has more of a theoretical rather than practical significance. Practically, calculating the level of element interactivity remains the only realistically applicable though simplistic means of estimating cognitive load imposed by specific tasks. However, this new theoretical perspective can potentially have implications for incorporating emotional processes into the framework of cognitive load theory, considering that emotions also usually change at the same shorter time scale (Ekman 1999). They may effectively become essential part of the processes contributing to the level of intensity of cognitive activities.

A number of cognitive load researchers have begun to consider the relation of emotion and cognitive load (Brünken et al. 2010; Fraser et al. 2015; Knörzer et al. 2016). Before we describe different ways in which emotion relates to cognitive load, we will turn to recent developments to incorporate affective variables such as motivation and emotion in some of the processing models of multimedia learning that are often used in conjunction with CLT.

Incorporating Emotion into Processing Models of Multimedia Learning

The CTML, even though it is based on a number of similar assumptions as cognitive load theory (dual processing channels, limited processing capacity), is effectively a processing model of learning (Mayer 2005, 2009). It considers learning as a combination of cognitive processes at three stages: (1) selecting relevant incoming information, (2) organizing selected information into coherent mental representations, and (3) integrating mental representations with other knowledge. One of the basic principles of this theory is that the use of both processing channels of working memory (visual and auditory) would effectively increase the flow of cognitive processes through the system.

Moreno (2005, 2006) and Moreno and Mayer (2007) proposed a Cognitive-Affective Theory of Learning with Media (CATLM), which expanded CTML by considering affective mediation. According to this theory, motivation, i.e., the processes that direct and sustain a person's behavior towards learning, mediates learning by influencing cognitive engagement of the learners. Moreno (2010) noted that cognitive load theory in its traditional formulation could not explain the performance of self-regulated learners who were capable of expanding on their effective cognitive capacity. She suggested that the Cognitive-Affective Theory of Multimedia Learning offered a more valid alternative. This theory treats learning as a result of the interaction between learner motivation, beliefs, affect, and knowledge. All these factors influence the regulation of cognitive processes, and as a result, determine principles of the effective instructional design.

Moreno (2010) stressed the importance of motivation in determining actual working memory resources allocated to the learning task (the resources that are now associated with germane cognitive load). Within the traditional framework of cognitive load theory, there were only some limited attempts to consider motivation. Paas et al. (2005) suggested that by introducing a motivational perspective on the relationship between mental effort and performance (instead of the traditionally used simplified linear relationship between mental effort and performance), cognitive load theory could be able to compare instructional conditions with regard to their effects on both efficiency and learner motivation. According to Moreno (2010), cognitive load theory needs to consider motivation as a critical component of a cognitively effective and efficient learning environment. Therefore, engaging learners to enhance their motivation should be treated as a valid purpose of learner activities.

In addition to Moreno's work on adding a focus on motivation, Plass and Kaplan (2016) proposed additional changes to Mayer's (2005) Cognitive Theory of Multimedia Learning by incorporating emotion as a separate processing channel. Their model, the Integrated Model of Cognitive-Affective Learning with Media (ICALM), goes beyond Moreno's (2005) CATLM model by giving emotion processing the same priority as the processing of visual and verbal information. By proposing a separate channel for emotion processing, the ICALM model allows for a reciprocal relation of emotion and cognition. For example, Plass and Kaplan (2016) describe that the selection of a graphical image may result in the experience of an emotion by the learner. Conversely, the learner's emotional state may determine which graphical image is selected in the first place, based on emotion-congruent learning, discussed below. Neither cognitive nor emotional processing is considered primary. A similar interplay of cognition and emotion takes place during the process of organizing information in working memory: the process of organizing specific information into coherent verbal or visual mental representations may induce emotions into the learner. Likewise, the learners' emotional state may determine whether and how this organizing of information will take place. The resulting mental model, then, is not only an integration of visual and verbal mental representations, but also includes emotional schemas (Plass and Kaplan 2016). The ICALM model was informed by other theories that describe the importance of considering academic emotions, such as the Control-Value Theory of Academic Emotions (CVT, Pekrun 2006), which describes antecedents and mechanisms of emotion processing during the learning process, Dual Coding Theory (DCT, Paivio 1990), which describes a verbal and a non-verbal system of information representation and processing, and by results from empirical research on the relation of emotion and learning, which will be discussed in the next sections.

In summary, advances in cognitive processing models of learning with media have added emotion processing as an important aspect of the learning process. We argue that cognitive load theory should do the same. Before we propose how such an integration of emotion into CLT could take place, we will discuss relevant research on emotion and cognition as well as emotion and learning to further highlight the relevance of considering emotion.

Emotion and Cognition

Emotions have been defined in many different ways, and no generally agreed upon definition has emerged (Pessoa 2008; Plass and Kaplan 2016). We therefore use the comprehensive definition of emotion provided by Russell's (2003) dimensional model of emotions for our discussion. In this model, core affect is a "neurophysiological state that is consciously accessible as a simple, nonreflective feeling" (p. 147). The model describes two basic dimensions: pleasure (experienced as pleasant vs. unpleasant) and arousal (experienced as activation vs. deactivation) (see Fig. 1).

The connection of emotion to neurophysiology is part of even the earliest theories of emotion, such as those proposed by James (1884) and Lange (1885). Later theories began to include a cognitive component, such as involving the labeling of emotion (Schachter and Singer 1962) or other cognitive appraisal processes (Lazarus 1991). However, despite several decades of affective neuroscience research, the neural basis of emotions is still being debated. Initial results indicated that the primary parts of the brain that process emotions are the limbic structures of the amygdala, hypothalamus, cingulate cortex, and primary frontal cortex. Also implicated were the thalamus, nucleus accumbens, ventral palladium, and hippocampus, among others (Dalgleish 2004). Emotional processing uses two pathways. The first, slower pathway, is from the thalamus, where an emotion such as fear is perceived, through the cortex and then to the amygdala. The second, much quicker pathway is from the thalamus directly to the amygdala (Cunha et al. 2010; LeDoux 1996, 2003). Whereas the faster pathway enables us to evade a potentially dangerous situation without having to first give it conscious thought, the slower pathway involves cognitive processing of the stimulus. The integration of emotion and cognition was for many decades thought to be a task of the hippocampus (MacLean 1949).

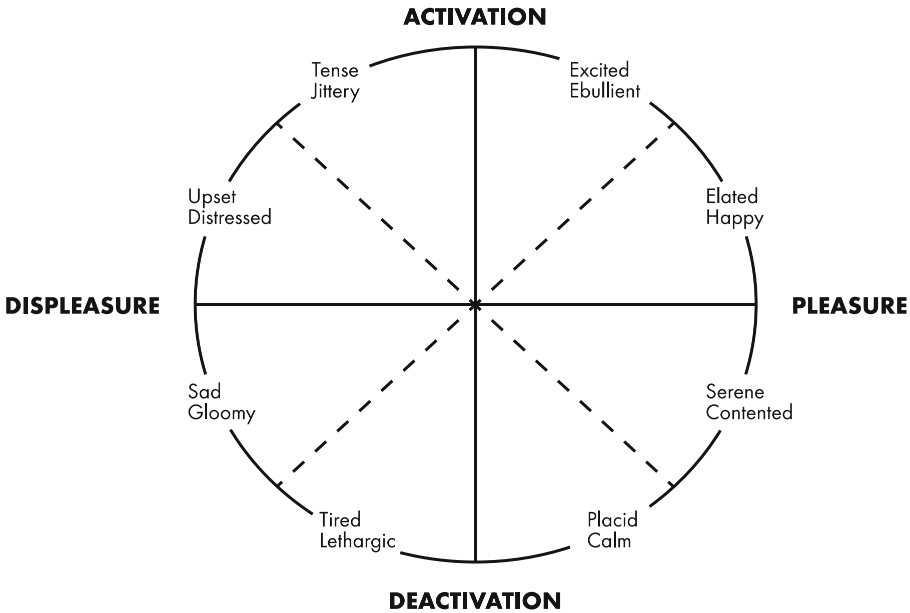

Fig. 1 Russell's dimensional model of emotions

Recent approaches are challenging the traditional focus on functional localization of emotion, and especially the separation of the brain into cognitive and affective regions (Pessoa 2008). In particular, critics argue that emotion and cognition are integrated in the brain, with affective regions of the brain involved in cognitive processing, and cognitive regions of the brain involved in affective processing (Pessoa 2008). They argue that the separation of emotion in the brain is not possible since "complex cognitive-emotional behaviour emerges from the rich, dynamic interactions between brain networks" (Pessoa, p. 148). Damasio (1994) even suggests that rationality and thought actually require emotional input. Other researchers take this argument yet a step further by suggesting that the brain mechanisms of emotion and cognition are not fundamentally different (LeDoux and Brown 2017). In fact, LeDoux and Brown suggest that "subcortical circuits are not responsible for feelings, but instead provide lower-order, nonconscious inputs that coalesce with other kinds of neural signals in the cognitive assembly of conscious emotional experiences" (p. E2016). In other words, emotions are not innately programmed into subcortical areas of the brain, such as the amygdala, but instead arise from the same general cortical system that processes cognition (LeDoux and Brown 2017). Indeed, Russel (2003) described emotional episodes as neither biologically nor socially determined, but rather psychologically constructed. As a result of this emphasis of construction, an emotional episode changes over time and can be seen as dynamic.

In summary, advances in affective neuroscience research have shown the interconnectedness of emotion and cognition, going so far as stating that both emerge from the same general cortical system (LeDoux and Brown 2017), and have highlighted the dynamic properties of emotion. This view is not yet fully reflected in the context of learning and teaching (Hawkins 2017), and we will review research on the relation of emotion and learning next.

Emotion and Learning

Even though emotions are ubiquitous in learning (Pekrun and Stephens 2010), research on the connection of emotion and learning has, for a long time, been largely limited to the study of negative emotions, such as test anxiety (Zeidner 1998), anxiety related to academic performance (Poropat 2009; Poropat 2014; Seipp 1991), or computer anxiety (Brosnan 1998). An example of such studies is research by Brand et al. (2007), which found that negative emotions during learning result in longer times required to reach mastery levels, and in lower performance on transfer tasks, compared to positive emotions. Research on negative emotions also found that learners in intelligent tutoring systems who experienced frustration and boredom had lower learning outcomes than learners not experiencing these emotions (D'Mello and Graesser 2012). However, some negative emotions, such as confusion, may also result in deeper learning (D'Mello et al. 2014).

A theoretical approach connecting emotion and learning is the *Control-Value Theory of Achievement Emotion* (CVT, Pekrun 2000), an integrative framework that describes the antecedents and effects of emotions experienced by learners. The theory describes how positive achievement emotions, for example, enjoyment, can facilitate learning because they give the learner a sense of autonomy. Research found that situations where learners experienced a high sense of control as well as a high positive task value resulted in positive emotions and increased learning outcomes (Stark et al. 2018a, b). Positive emotions are also thought to establish the intrinsic value of the learning material (Pekrun 2006; Pekrun and Stephens 2010). Negative academic emotions, on the other hand, predict low student achievement (Pekrun and Linnenbrink-Garcia 2012). Yet in other research, negative emotions induced before learning facilitated learning (Knörzer et al. 2016). A more detailed discussion of CVT, as well as of recent research related to it, is beyond the scope of this paper but can be found in the excellent review by Pekrun and Perry (2014). Readers interested in the application of CVT to emotion in game-based learning can find more information in Loderer et al. (2019).

Emotional design describes the use of a number of design features of learning environments with the goal to elicit emotions that enhance learning or cognitive skills development (Plass and Kaplan 2016). Unlike designs that add *seductive details* that require additional processing (Harp and Mayer 1998), emotional design does not add any new content to the environment that needs to be processed and that would compete for cognitive resources. Instead, it uses design features that are inherent to the environment, such as colors, shapes, expressions of characters, or sounds, and manipulates the affective qualities of components of the environment. For example, increased musical tempo has been found to increase arousal, and warm colors have been shown to induce positive emotions (Loderer et al. 2019).

The use of specific design features to induce emotions for a learning task is based on theoretical and empirical findings in order to achieve the desired effect on the learners' emotional state. For example, before designing games with high versus low emotion arousal, researchers studied how different designs of game characters, which used color, shape, and expression as features to induce emotion, affected learners' emotion arousal (Plass et al. 2019). After determining which designs induced high versus low emotion arousal, a second study was conducted to determine the effect of these designs on learning outcomes (Homer et al. 2018). Emotional design is a complex task; however, and in some cases, the emotion experienced during the learning process was different than the one reported in the study verifying the materials (Navratil et al. 2018).

The term emotional design for learning was coined by a study investigating the effect of positive emotions on learning outcomes (Um et al. 2012). The study used shape and color of digital learning materials to induce positive versus neutral emotions. This research, conducted with college students, showed that round shapes and warm colors can induce positive emotions, and that these positive emotions can facilitate comprehension and transfer of learning scientific materials (Um et al. 2012). Importantly, results showed that cognitive load, measured by a self-report of perceived task difficulty (Kalyuga et al. 2000), was lower in the positive emotion group, with a medium effect size. A follow-up study was able to largely replicate this effect and decompose the effects of color and shape on emotion (Plass et al. 2014). An additional study confirmed this emotional design effect for a different subject matter, showing that positive emotions induced by using shape and color result in enhanced learning about viruses (Mayer and Estrella 2014). Here, learners in the emotional design group reported higher investment of mental effort, with a medium effect size in one of the two experiments. Another study used eye tracking to further investigate this effect. This research found similar improvements of comprehension and transfer for the positive emotion group, and showed longer fixation durations on relevant learning materials for this group (Park et al. 2015a, b).

In the context of learning from web-based materials, the usability of the web design emerged as another emotional design factor, with higher perceived usability leading to higher learning outcomes (Heidig et al. 2015). Other studies, however, have not found effects of emotional design. For example, research investigating the effect of emotion on self-generated learning activities did not find an effect of positive versus negative valence of emotion on retention or transfer (Navratil and Kühl 2018).

More recently, the concept of emotional design has been extended from visual materials to the design of texts. Among the methods to induce different emotions in a text are the use of emotion words (e.g., angry, happy), emotional interjections or exclamations (e.g., ewww!, yay!), or by referring to the emotional potential possessed by all words (Schwarz-Friesel 2007). A study comparing three texts that were designed to induce positive, neutral, or negative emotions found that both positive and negative designs resulted in enhanced elaborations and, as a result, in increased learning, even though only a small to nonsignificant effect of the emotional text design on emotion was found (Stark et al. 2018a, b).

Similar results were found in the context of using simulations in medical education. One study (Fraser et al. 2014) induced emotions by providing two different outcomes of a simulation on a patient presenting with reduced consciousness. In one group, the patient experienced a cardiorespiratory arrest and died, while in the other group, the patient was transferred to another service and lived. Students in the group where the patient died reported more negative emotions, such as stress and nervousness, and experienced higher cognitive load and lower learning outcomes in a similar simulation three months later compared to students in the group where the patient lived. These findings were similar to previous research in which students' experienced emotion during learning with a simulation was related to their experienced cognitive load and learning outcomes. The experience of pleasant activating emotions was related to higher experienced cognitive load, whereas the experience of pleasant deactivating emotions was related to lower cognitive load. Cognitive load and learning outcomes were negatively related for performance on the trained task (Fraser et al. 2012).

Research investigating the effect of emotion on the development of cognitive skills has found similarly interesting effects. In a study comparing two versions of a game designed to help learners develop their executive functions, participants played either a game with neutral design, featuring game characters design as square shapes and in black and white, or a game with positive design, featuring game characters design as round shapes and in warm colors. The cognitive skill targeted was the executive function sub-skill of shifting, sometimes also referred to as cognitive flexibility. Results showed that learners playing the game with the positive emotion design had higher gains in shifting skills, especially learners with low levels of prior executive functions and learners in late adolescence (Homer et al. 2018).

In summary, there is empirical evidence that emotions have an effect on learning, and some, albeit sparse evidence, that cognitive load is directly affected by learners' experienced emotions. The sometimes conflicting findings of how emotion affects learning suggest that different mechanisms are at work. We therefore discuss four different ways in which we can consider the effect of emotion on cognitive load.

Four Ways of Considering Emotion in Cognitive Load Theory

Research has produced results that can be described in four different ways of considering emotions in the context of cognitive load theory. These groupings are often not completely independent from one another, but we believe they allow for a more systematic understanding of the relation of emotion and cognitive load, and provide directions for future research on this issue.

Emotion as Source of Extraneous Cognitive Load

A common way in which emotions have been considered in CLT is as a source of extraneous cognitive load. Here, the effects of emotions have been described as *suppression hypothesis*, based on Ellis and Ashbrook's (1988) resource allocation theory of depression. Two mechanisms have been identified in this respect: Emotion can either lead to the allocation of resources to extra-task processing, i.e., thinking about one's emotional state, or to task-irrelevant processing, i.e., processing information not related to the learning outcome (Oaksford et al. 1996).

Task-extra processing includes appraisals and other processes involved in emotion and emotion regulation that make demands on cognitive resources as they generate thoughts that need to be processed (Pekrun 2000). Since these processes are not thought to be contributing to the learning goal, they are considered extraneous cognitive load. Examples for task-extra processing due to learners' emotion include the literature on test anxiety (Zeidner 1998) and on stereotype threat (Steele and Aronson 1995). Anxiety is thought to lead to worry, which can lead to the reduction of the storage and processing capacity of working memory, but may also increase the amount of effort invested in a task (Baddeley 2012; Eysenck and Calvo 1992). Stereotype threat may involve similar mechanisms in which members of a negatively stereotyped social group experience anxiety about their performance, and where processing of the resulting emotions may result in reduced outcomes (Steele and Aronson 1995).

Another example of negative affect is stress, induced by pressure to perform, which can fill working memory with thoughts about the situation and one's performance, effectively reducing the amount of working memory that is available to perform the task at hand (Beilock et al. 2004). In other words, in situations involving negative emotions such as stress, thoughts about one's emotions, processes of emotion regulation, and the actual learning task all compete for the limited working memory resources. Results from negative emotion experienced during learning from simulations in medical education have also been interpreted as source of extraneous cognitive load that resulted in reduced learning due to task-extra processing (Fraser et al. 2015). This effect, which can also be found for positive emotions, has in some studies been linked to the depletion of central executive resources (Oaksford et al. 1996).

Task-irrelevant processing occurs when induced emotions lead to the spontaneous retrieval of material that has to be processed. When this material is not relevant to the learning goals, the processing of this irrelevant information induces extraneous cognitive load (Seibert and Ellis 1991). In general, both positive and negative emotions could result in task-irrelevant thinking that can generate extraneous load (Pekrun and Linnenbrink-Garcia 2012).

One example of task-irrelevant processing is described by the *seductive details effect* (Park et al. 2011). This effect describes how the addition of irrelevant but interesting details to learning materials in order to make them more interesting can result in reduced learning outcomes (Harp and Mayer 1998). The extraneous cognitive load generated by the task-irrelevant processing of these materials is more harmful than the benefit obtained from making the materials more interesting. This is especially the case when seductive details increase the cognitive load experienced by the learners (Park et al. 2011), but the effect can be compensated by offloading the seductive details to another modality (Park et al. 2015a, b).

Task-extra and task-irrelevant processing describes an important aspect of the interplay of emotion and cognition, yet it is largely focused on the interpretations of the negative effect of emotions on cognitive load and learning. Some of the more recent research results cannot be explained by this view, and we will discuss alternative approaches below.

Emotion as a Factor Affecting Memory

Another way to describe the relation of emotion and cognitive load is by considering the effect of emotion on memory. Research has shown that emotion modulates memory even at the earliest stages of perception. The amygdala is able to respond to an emotional stimulus in the environment before awareness (Whalen et al. 1998), even without attentional focus (Anderson et al. 2003). This is thought to enhance later perception and lead to enhanced encoding for emotional events, but also facilitates attention on the emotional event (Phelps 2004). The fact that emotional arousal focuses attention on the central gist information is, in fact, considered an evolutionary advantage (LaBar and Cabeza 2006).

Working memory may be affected by emotion in different ways. These include enhanced encoding, broadening or narrowing of resources, and mood-dependent encoding and retrieval.

For example, positive affect is a signal that an individual's needs are taken care of, allowing for other goals and needs to be addressed (Carver 2003). This is thought to have a broadening effect that may increase the amount of cognitive resources available for learning (Fredrickson 1998, 2001). In fact, research has shown that positive affect leads to outcomes that can be interpreted as indicators of more available working memory, such as increases in creativity (Isen 1987; Isen et al. 1987) and increases in pro-social behavior (Isen and Levin 1972). Because of these benefits, this effect has been described as the *facilitation hypothesis* (Isen 1987; Isen and Means 1983; Isen et al. 1987). One mechanism of the facilitation hypothesis is that positive affect can serve as a retrieval cue for positive material from long-term memory (Laird et al. 1982), which has also been described as long-term working memory (Ericsson and Kintsch 1995). Another mechanism is that positive mood may affect the cognitive processes themselves, not only by broadening available resources and enabling creative thinking (Isen et al. 1987), but also by an improved use of the available cognitive resources (Bless et al. 1996) and facilitation of executive processes (Levens and Phelps 2008).

Negative affect, on the other hand, is a signal that particular needs or goals are not yet sufficiently addressed. This may have a narrowing effect that decreases the amount of cognitive resources available for learning (Fredrickson 2003). Research has found effects of negative affect that can be interpreted as indicators of less available working memory (Curci et al. 2013; Plancher et al. 2018), which can result in decreases in creativity (Isen et al. 1987) and reduced learning outcomes (Pekrun and Linnenbrink-Garcia 2012), and which may not be explained as task-extra or task-irrelevant processing (Fraser et al. 2015).

Consider, for example, the well-established effect of *mood-dependent memory*, which refers to the effect that recall of material is better when the mood at retrieval is the same as at encoding (Bower 1981; Lewis and Critchley 2003). A related effect is *mood-congruent memory*, which describes that new material is more likely to be encoded when the learners' mood at the time of encoding matched the mood associated with the material to be learned (Lewis and Williams 1989). The exploration of the neuronal substrate underlying these effects revealed that successful encoding and retrieval are differently modulated by the learner's emotional state. In a study involving learning of neutral items, both encoding and recognition of the items involved activation of the hippocampus and parahippocampal gyrus when learners were in a positive mood. When learners were in a negative mood, encoding was associated with activation of the anterior temporal cortex, a region with afferent connections to the amygdala. Retrieval, however, was associated with activation of the caudate nucleus (Erk et al. 2005). These findings suggest that learning may be more efficient in a positive mood, since the same neural circuits are recruited for both encoding and retrieval, which was not the case for learning in a negative mood. Other research involving the induction of pleasant, neutral, and negative emotional states in participants found that the negative condition was associated with poor temporal and spatial memory, whereas the positive condition was associated with better spatial memory (Zlomuzica et al. 2016). These examples show how research investigating the neural correlates to the concept of working memory have begun to identify mechanisms that may explain the effect of emotion on working memory in a way that is useful in the context of cognitive load theory, but more research is required to clarify this connection.

Long-term memory has been shown to be modulated by emotion in other ways as well. Storage of emotional memories involves consolidation, which turns memories that are still fragile and prone to disruption into more stable memories for which retrieval is less dependent on the hippocampus (Phelps 2004). Research found that emotional advantages in memory are not experienced immediately, but after a certain time interval. This suggests that emotion facilitates consolidation processes in long-term memory (Kleinsmith et al. 1963; Sharot and Phelps 2004). In fact, the amygdala appears to mediate the influence of emotion arousal through mechanisms that involve a large range of memory functions in other brain regions, including the cerebellum, sensory neocortex, medial temporal lobe memory system, and prefrontal cortex, which includes working memory (LaBar and Cabeza 2006). Many of these mechanisms are still the subject of ongoing research, but these investigations concern how emotion affects memory, not whether such an effect does or does not exist.

Emotion as Intrinsic Cognitive Load

A third perspective describes how emotion may affect intrinsic cognitive load. We will discuss Dual Coding Theory and the dual channel assumption for emotion, and learning in domains such as medical education where emotions are part of the learning outcomes.

The most straight-forward way for emotion to affect intrinsic cognitive load is in cases where affective outcomes are part of the learning goals. For example, in medical education, students need to learn to deliver bad news to patients or to deal with the death of a patient. In these cases, emotion regulation is part of the learning objectives, and processing or regulating emotions is therefore essential, making it a source of intrinsic cognitive load (Fraser et al. 2015). In the studies on simulated patient death described above, students who experienced higher levels of emotions reported higher cognitive load and showed lower learning outcomes on the performance tasks (Fraser et al. 2014), though affective outcomes, such as improvements in students' ability to regulate their emotion, were not separately measured in this study.

Another way to consider emotion in relation to intrinsic cognitive load is in the context of DCT (Paivio 1990). Dual Coding Theory is a cognitive theory that describes how information is processed in two representationally distinct but functionally related systems, a verbal system for linguistic information, and a non-verbal system for imagistic information (Paivio 1990). The verbal system represents language symbols, while the non-verbal system represents a range of modality-specific visual, auditory, or haptic information, as well as tastes, smells, and emotions. Representations within each system are linked by associative connections, and referential connections link representations between systems. Since both systems are considered relatively independent from one another, processing of information in one system does not interfere significantly with processing of information in the other system. This, along with the working memory model proposed by Baddeley (1986), forms the foundation of the *modality effect*, which describes that learning is increased when multimedia materials present verbal information that accompanies visuals as auditory information (e.g., as a narration) rather than as visual information (i.e., as on-screen text). The explanation of this effect is based on the idea that by offloading the verbal information from the visual to the verbal channel, the verbal information can be processed separately from the visual information presented in the non-verbal channel, and therefore does not compete for the same cognitive resources (Mayer 2001). This effect has been found to be especially strong under system-controlled pacing of learning (Ginns 2005).

While it is not clear whether emotions can be used for offloading in a way similar as described by the modality effect, the processing of emotion appears to use a different channel than visual or verbal processing. Evidence for such a *dual channel assumption for emotion* comes from research on learning concrete versus abstract words which has shown an advantage for concrete words that has been attributed to the emotions they evoke (Bradley et al. 1992; Goetz et al. 2007). Also supportive of this idea is that emotion can serve as additional retrieval cue for information committed to long-term memory (Isen et al. 1978). As a result, Paivio (2007, 2013) stresses that there is sufficient empirical evidence supporting a dual coding theory of emotion. The study of neural correlates of memory has revealed two structures, located in the medial temporal lobe, that are linked to independent memory systems (Phelps 2004). The first one, specializing in emotion processing, is linked to the amygdala. The second, linked to the hippocampal complex, processes declarative and episodic memory (Phelps 2004). This notion of independent systems is also supported by results from fMRI functional connectivity analyses comparing interregional brain activity correlations during the recall of traumatic memories in posttraumatic stress disorder (PTSD) patients versus controls without PTSD, which showed that only the PTSD patients had an unusually high connectivity among regions processing verbal and traumatic emotional material (Lanius et al. 2004). This dual channel view is compatible with the ICALM model, in which the processing of emotion takes place in a different channel than the processing of visual and verbal information, but still needs to be validated in the context of cognitive load theory.

Emotion Affecting Motivation to Increase Cognitive Effort

A final perspective of the relation of emotion and cognitive load is by considering the effect of emotion on motivation. In this view, which especially corresponds to the first level in the taxonomy of learning goals proposed by Kalyuga and Singh (2016), the effect of emotion on learning is mediated by motivation. It has been argued that emotion, regardless of valence, can foster motivation that will result in increased learning (Pekrun 2006).

For positive emotions, this perspective is supported by research that has shown that positive emotions facilitate intrinsic motivation (Erez and Isen 2002; Isen and Reeve 2005). In the context of emotional design, the features used to induce positive emotions, such as warm colors or round shapes, may make the learning environment more motivationally pleasing and may, as a result, increase motivation (Heidig et al. 2015). This effect is more likely for activating positive emotions; deactivating positive emotions can have the opposite effect by deactivating motivation and resulting in disengagement from the learning process (Pekrun and Linnenbrink-Garcia 2012).

The explanation of this effect for negative emotions is not quite as straightforward (Knörzer et al. 2016). An argument advanced here is based on the *mood repair* hypothesis, which describes how learners in a negative emotional state may seek to improve their affect as a form of an evolutionary motivational tendency (Bless and Fiedler 2006). As part of this emotion regulation, learners may turn to a learning activity in order to shift their attention away from their negative emotional state (Knörzer et al. 2016). Although interesting from a theoretical perspective, this potential of negative emotions to increase motivation has only very limited empirical support (Knörzer et al. 2016). Perhaps a more likely mechanism for negative emotions is that they may induce motivation to avoid failures by investing effort, and thereby increase academic motivation (Pekrun and Linnenbrink-Garcia 2012).

One example of emotion facilitating motivation may be the *personalization effect*. This effect describes how the use of personalized speech, via personal pronouns, can result in increased learning outcomes when learning from multimedia science materials (Moreno and Mayer 2004). One of the explanations of this effect is that personalization results in higher motivation (Rey and Steib 2013), possibly as the result of positive emotions induced by the use of personal speech. This is supported by research investigating whether the personalization effect was moderated by learners' emotion, which found that the facilitating effect of addressing learners in the first person disappeared, and in some cases was even reversed, when the subject matter induced anxiety in learners (Kühl and Zander 2017).

Discussion

We have discussed four ways in which emotion may relate to cognitive load during learning. One perspective describes emotions as extraneous cognitive load, competing for the limited resources of working memory by requiring the processing of task-extra or task-irrelevant information. Another perspective shows that emotion may directly affect memory, by broadening or narrowing cognitive resources such as working memory, and by mechanisms such as mood-dependent and mood-congruent processing, which may relate to the different neural correlates in which emotion is processed. We also discussed how encoding, storage, and retrieval of information is affected by emotion even before awareness of the material. A third perspective describes emotion as affecting intrinsic cognitive load, which is the case in situations where emotion regulation is part of the learning outcomes. An interesting area to explore related to intrinsic cognitive load is whether predictions of Dual Coding Theory related to emotion, which suggest that there may be a separate processing channel for emotion, have implications for intrinsic cognitive load. Finally, the relation of emotion and cognitive load may be mediated by motivation. In this perspective, emotion may result in increased or decreased motivation to expend cognitive effort.

Given the often contradictory findings related to emotion and learning, it is likely that in different contexts, for different subject matter areas, and for different learners, one or more of these perspectives of relating emotion and cognitive load may apply. It is also likely that during different phases of a learning task, the way in which emotions affect cognitive load may change. This change can be due to the changing sub-goals that need to be achieved for a particular learning activity, changes in the learners' emotions, and even depletion of cognitive resources over time (Clarkson et al. 2011). For a theoretical discussion of the connection of emotion and cognitive load that can accommodate these changes, we require a description of CLT that views cognitive load as a local, micro-level characteristic of working memory operation, such as Kalyuga and Singh's (2016) interval definition of CLT. Since in this view cognitive load is associated with relatively short-term, local episodes of learning activities that are directed towards specific local goals, a learner's experienced emotion can be considered on the same time scale.

As described above, when taking an interval view of learning as a sequence of local learning episodes, then cognitive load becomes a local, micro-level characteristic of working memory operation associated with relatively short-term, local episodes of learning activities. These episodes occur within the timescale of working memory operation and are directed towards specific local goals. Motivating and engaging learners with a learning task are examples of such local goals. Emotional episodes, as defined by Russell (2003), have a similar dynamic quality as these learning episodes, and are likely linked to specific parts of a learning activity rather than the activity as a whole.

Taking the interval view of cognitive load means that we consider various types of learner activities with different specific types of goals. Some of these goals (such as the acquisition of domain-specific knowledge structures) may be best achieved through the means traditionally supported by cognitive load theory (such as providing novice learners with explicit instructional guidance based on the worked example effect). However, other types of goals (especially those related to enhancing learner motivation or influencing their affective states) may require different instructional approaches. These may involve the design of activities with higher levels of learner control, as described by the Control-Value Theory, such as those involving exploration and problem-solving activities. Or they may involve the use of activities or designs to induce emotion to facilitate learning, as described by emotional design. In these cases, research should explicitly focus on whether the negative effects of cognitive overload on learning domain-specific schemas that have been well established in cognitive load theory can be offset using strategies that enhance emotion or motivation.

In order to gain a deeper understanding of issues of load related to learning activities that may serve an affective function, we can take advantage of the three-level taxonomy of goals of learner activities described by Kalyuga and Singh (2016). The pre-instruction goals intend to create cognitive, emotional, or motivational prerequisites or conditions for further learning, for example, activating learner relevant prior knowledge, inducing a positive emotional state, or motivating to learn and engaging with the learning task. The next level of goals is related to the actual acquisition of domain-specific knowledge structures, and may involve the use of emotions to enhance learning in one of the four ways discussed above. The third level of goals could be related to learning higher-level, generalized knowledge such as general conceptual frameworks or principles and heuristics in a domain to guide learner flexible performance on far transfer tasks. Only the second level (acquisition of domain schemas) has been traditionally the focus of cognitive load theory. The "pre-instruction" and higher-level goals are usually considered in alternative approaches.

This view leads to interesting new interpretations of some existing findings in the literature. For example, a study involving the game *Crystal Island* found that learners' off-task behavior was generally related to negative learning outcomes (Sabourin et al. 2011). In a closer inspection of these findings, however, Sabourin et al. (2011) found that some of these off-task behaviors were used for emotion regulation. Applying the interval definition of cognitive load related to specific goals and sub-goals, a behavior that would be considered off-task in one sub-goal, and therefore a source of extraneous cognitive load, becomes an important preparation of the next sub-goal, for which the positive emotions that are the result of the emotion regulation may result in increased learning outcomes. For the following sub-goal, therefore, the same behavior can be considered on-task, and may generate the motivation required to increase the intensity of the cognitive activity, or mental effort investment.

Our discussion of ways in which emotion is related to cognitive load was in part derived from advances in affective neuroscience that have shown that a functional separation of emotion and cognition can no longer be supported by the available research evidence, and that the processing of emotion and cognition involves highly connected cortical networks. We included in our discussion studies that were not conducted in a specific cognitive load context, and for which we proposed connections to cognitive load. This paper should therefore be seen as a call to conduct research on the relation of emotion and cognitive load, a call to investigate how emotions can be induced with different forms of emotional design, which approach to relating emotion and cognitive load apply under which circumstances, and, using an interval view, what the temporal progression of the experience of emotion and cognitive load is during learning, and how that affects learning outcomes.

Conclusion

In this paper we described four ways in which emotion could be considered in the context of cognitive load theory and discussed research from affective neuroscience, educational psychology, cognitive psychology, positive psychology, and many other subdisciplines. We first summarized recent advances in CLT, including Kalyuga and Singh's (2016) interval view of cognitive load. We then described process models of multimedia learning that have recently begun to incorporate emotions in addition to cognitive processing. We next summarized recent advances in affective neuroscience that showed the inseparable nature of emotion and cognition, and discussed research on emotion and learning. We then discussed four ways in which emotion can be related to cognitive load: Emotion can be a source of extraneous cognitive load, emotion can affect virtually all forms of memory, emotion can be a source of intrinsic cognitive load, and emotion can have an effect on learners' motivation.

In order to determine which of these mechanisms may apply, and under what conditions, we adopted an interval view of cognitive load, which describes the nature of cognitive load as a phenomenon within a broader theoretical perspective as the intensity of the cognitive activity required for achieving a specific goal (Kalyuga and Singh 2016). Accordingly, the cognitive load for achieving such a goal is determined by all those cognitive processes that need to be performed within the timescale of working memory operation to achieve the goal. This approach effectively combines the consequences of both limited capacity and limited duration of working memory. The focus on timescale and cognitive activities considers cognitive load as a fundamentally local, micro-level characteristic of cognitive processes rather than a macro-level characteristic associated with more extended time periods or materials. Selecting optimal sequences of goals and corresponding learner activities is treated as a key issue in designing effective learning tasks. A critical category of goals that needs to be included in this process are those related to inducing an emotional state conducive to learning and to motivating and engaging learners with a learning task. The emotions experienced by the learners during processing can have such a motivating function, broaden available cognitive resources, or allow for reduction of intrinsic load, or using emotion as a retrieval code. Emotion may of course, also narrow cognitive resources or increase extraneous processing requirements.

Combining perspectives of emotional influences on cognitive load with an interval view of CLT will hopefully result in an expanded view of cognitive load that better captures the complexity of human learning, and thereby provides a more comprehensive guidance for the design of learning environments.

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