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Well-Being as a Cognitive Load Reducing Agent: A Review of the Literature

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Cognitive Load Theory is an evolutionary based theory of learning centered upon the cognitive architecture of the brain, which outlines a series of empirically based instructional effects that ensure efficient and effective learning. While the research upon which Cognitive Load Theory is based has generally aimed at controlling the impacts of the surrounding environment, the impact of individual psycho-social factors such as a student's level of well-being have not, as yet, been fully explored. This review was conducted using the Scopus database focusing on the Cognitive Load Theory Instructional Effects literature. The review proposes that well-being may act as a cognitive load reducing agent for students and offers evidence from the broader literature on mechanisms through which well-being reduces the cognitive load placed upon a student's working memory. The proposed mechanisms of reducing extraneous load and increasing germane load are proposed through; the presence of positive emotions, the absence of painful emotions, high levels of academic buoyancy, and cognitive regulation.

Keywords: well-being, academic buoyancy, emotions, cognitive load, learning

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INTRODUCTION

The explicit teaching of well-being skills is a growing area within the Education system in Australia (Slemp et al., 2017). The majority of the research upon which the positive psychology and well-being literature is based focuses on the social and emotional aspects of well-being and is referred to as social and emotional learning (SEL: Elias et al., 1997). While research from the field of positive psychology demonstrates a significant positive relationship between the social and emotional well-being of students and their academic achievement (Berger et al., 2011; Durlak et al., 2011) how well-being interacts with and impacts learning, rather than just academic achievement, is currently an area of omission within the positive psychology literature.

According to Cognitive Load Theory (CLT), learning occurs when information is processed and moved from working memory into long term memory with this new information being effectively "stored" in long term memory which can be later retrieved as required (Kirschner et al., 2006). To date, CLT research has predominantly explored how information that is to be learned should best be presented to maximize learning and reduce a load on working memory and the instructional implications of these findings (Sweller et al., 2011); however, the impact of complex, multidimensional psycho-social factors such as a student's level of well-being has not, as yet, been fully explored. This paper aims to review the positive psychology and cognitive psychology literature to identify how student well-being may influence learning. The review will outline CLT, define the construct of well-being, briefly summarize the method used to conduct the review of the CLT Instructional Effects and explore how well-being most likely interacts with learning under the framework of CLT.

COGNITIVE LOAD THEORY

CLT focuses on the constraints of working memory in humans and is a theory used to help determine what kinds of instruction and pedagogies are effective for student learning. There are three components to CLT; (1) cognitive architecture explained through evolutionary principles, specified as the natural information processing system (Sweller and Sweller, 2006), (2) the division of cognitive load into three categories, which are additive in nature. Intrinsic load relates to the complexity of the material or skill to be learnt; extraneous load relates to the cognitive activities that do not contribute to learning; and germane load contributes directly to learning (Sweller et al., 1998), (3) instructional effects that take into account the limitations of the human cognitive architecture and different cognitive loads. CLT assumes a cognitivist perspective of learning, where learning is defined as the alteration of long term memory (Kirschner et al., 2006). As CLT relies on working memory altering long term memory, it assumes that, from an evolutionary perspective, human learning can be split into two distinct categories (Geary, 2002, 2008, 2012). Firstly, *biologically primary knowledge* which is information and skills that we have evolved to acquire without explicit instruction and as such is not limited by the cognitive architecture of the brain. We do not have to determine how to process the elements of this information as we have evolved to be able to do so. The skills of recognizing faces, and learning to speak are both complex processes that are examples of *biologically primary knowledge* that do not require explicit instruction. Secondly, *biologically secondary knowledge* is the acquisition of culturally important information and skills that allow people to cope with novelty and change within their lifetime. This information and associated skills require the use of working memory and controlled problem solving. *Biologically secondary knowledge* is related to knowledge that is useful in the social milieu in which a group is situated. The use of algebra in the domain of Mathematics offers an example of *biologically secondary knowledge*. Humans have difficulty acquiring this knowledge and often require extrinsic motivation to acquire relatively small amounts of knowledge. This usually requires explicit instruction and a conscious effort by learners as the limitations of working memory are directly relevant to the acquisition of *biologically secondary knowledge*. Geary's (2008) evolutionary account of educational psychology suggests that working memory has only limited importance when acquiring *biologically primary knowledge*. In contrast, working memory restrictions may be critical when acquiring culturally important information, or *biologically secondary knowledge* (for a detailed review see Sweller and Sweller, 2006). The work of Geary, Sweller and their colleagues implied that *biologically primary* vs. *biologically secondary knowledge* is constructed as a dichotomy; however, research by Pretz et al. (2010) provides evidence that *biologically primary* and *biologically secondary knowledge* may lie at either end of a continuum rather than two distinct categories of knowledge.

Cognitive Architecture Explained Through Evolutionary Principles

According to Sweller and Sweller (2006), there are five basic evolutionary principles used to describe human cognitive architecture. The five principles can be viewed as a natural processing system as they apply to natural systems such as evolution, natural selection as well as cognition.

Figure 1 outlines the evolutionary principles diagrammatically, with each of the five principles discussed in detail below.

1. The information store principle states that natural information processing systems require a very large store of information. For humans, long term-memory provides this store and, as a result, the bulk of human cognitive activity is directly determined by long-term memory.

2. The narrow limits of change principle states that only small amounts of novel information can be assimilated at any given time. Accordingly, a limited capacity, limited duration working memory ensues that when dealing with new information only small amounts of information are dealt with. Working memory

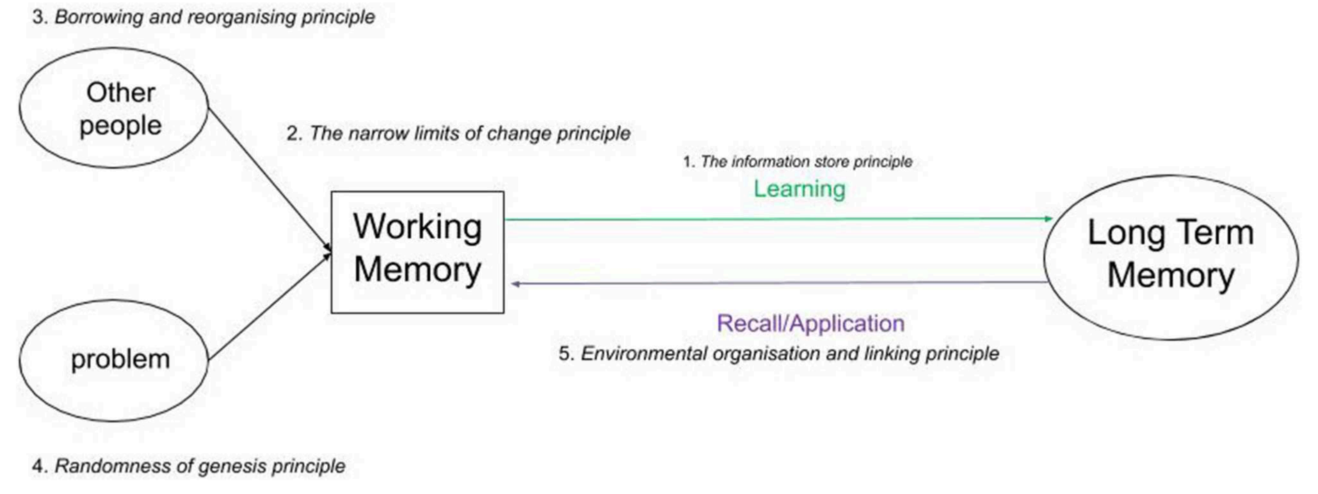

FIGURE 1 | Evolutionary principles of the cognitive architecture.

is characterized as the part of human cognitive architecture where information that is undergoing active processing is held. Working memory is considered to have a very limited capacity—most Cognitive Load theorists assume no more than seven chunks of information can be maintained simultaneously (Sweller et al., 1998); however, more recent research has shown that this maximum may be even more limited to five plus or minus two chunks of information (Renkl and Atkinson, 2003). According to Baddeley (1992), working memory contains two distinct subsystems; one for processing visual information (visual spatial) and a second subsystem for processing acoustic information (phonological loop). When simultaneous demands of visual and acoustic information are placed on working memory these demands can be distributed across the respective subsystems—helping to maximize working memory's capacity to store and process information. CLT suggests that when students engage in cognitive activities far removed from their prior knowledge and experience, a cognitive load is generated—primarily within the working memory—by the irrelevant activities, skills, and information ultimately impeding learning and skill acquisition.

A recent study by Chen et al. (2017) provides an extension to *the narrow limits of change principle,* by suggesting that working memory may not be fixed in its capacity but may in fact demonstrate a depletion effect. Chen et al., demonstrated that a depletion effect occurred on working memory when 30 primary school students (mean age of ∼10 years) were presented with massed mathematics learning tasks with no gaps between learning episodes. These students obtained lower scores on working memory capacity tests immediately after the learning tasks compared with 24 primary school students (mean age of ∼10 years) who were presented with the same mathematical tasks spaced by temporal gaps between learning episodes. This research suggests that *the narrow limit of change* narrows even further immediately following cognitive effort but is capable of expanding again following a period of rest. However, the time in which it takes to expand to its original level is not yet understood.

3. The borrowing and reorganizing principle allows for the building of a large store of information by borrowing and reorganizing information from other stores. In humans, most of the information stored in long-term memory is borrowed—in the form of schema—from the long-term memories of other people through imitation, listening to what they say, or reading what they have written. While most information in long-term memory is borrowed, it is mostly borrowed and reorganized to construct a new and meaningful representation of this information. Schema theory (Chi et al., 1982) is used to describe this process. Schema theory assumes that knowledge is organized into units, schemata, and stored in long term memory. Schemata represent knowledge about concepts, objects, and the relationships amongst them. In essence, the mental structure of preconceived ideas.

4. The randomness of genesis principle has the primary purpose of the creation of new knowledge. During problem solving, when current knowledge about the appropriate step in the problem solving process is lacking, steps must be randomly generated and then tested for effectiveness, with effective steps then stored in long-term memory and ineffective steps discarded.

5. The environmental organization and linking principle states that when working memory is dealing with information from long-term memory there are no known limitations when processing this information from long-term memory. That is, when recalling information already stored in long-term memory, it does not limit working memory or produce a cognitive load on working memory.

Therefore, according to CLT, well-being can promote learning through three evolutionary principles of learning:

1. Reducing the load on working memory—in accordance with the narrow limits of change principle.
2. Improving the borrowing and reorganizing principle and allowing more seamless information transfer from other people.
3. Maximizing information transferred from working memory into long term memory through more efficient use of the information store principle.

Three Categories of Cognitive Load

CLT asserts that learning activities should be designed to minimize the demands placed on working memory. Sweller et al. (1998) outline that there are three different types of cognitive load placed upon working memory and these loads are additive in nature.

Intrinsic load—refers to the complexity of the material or skill to be learnt. It specifically refers to the number of elements that the learner must attend to for understanding the material being learned. When there is a large number of interacting elements, element interactivity is described as high. A high intrinsic load is caused when a novice learner experiences a high degree of element interactivity. For example, a simple single digit division problem in Mathematics presents a lower intrinsic load than a more complex multiple digit division problem which includes a remainder. In other words, intrinsic load is dependent on the complexity of the learning content being relevant to the learner's level of prior knowledge. According to Sweller et al. (2011) more effective teaching pedagogies should help minimize intrinsic load by ensuring the complexity of the learning content is appropriate to the level of the learner's prior skills and knowledge.

Germane load—refers to demands placed on working memory capacity that contribute directly to learning. Germane load is determined by the learning goal and is often associated with the construction of schema (Sweller et al., 1998). For example, when completing a long multiplication Mathematics problem, the algorithm or process the student follows is the germane load. This type of load is contributing to whatever is the focus of the learning task, skill, or concept. More effective teaching pedagogies should have a high germane load (Sweller et al., 2011).

Extraneous load—is caused by cognitive activities that do not contribute to learning. As with germane load, what constitutes extraneous load is dependent upon the goal of the learning task (Sweller, 1994), however extraneous load will ultimately restrict learning, whereas germane load supports learning (for a full review see: Sweller et al., 2011). For example, if a student is attempting a problem using instructional material that requires the integration of complex text and diagrams, this would lead to a high extraneous load where much of the student's cognitive capacity is taken up attempting to bring a sense of coherence between the multiple sources of information, leaving minimal, if any room for germane load.

Paas et al. (2003, 2004) outline that the three different cognitive loads are additive and it is important not to induce a high extraneous load (cognitive activities unrelated to the learning process), particularly when paired with a high intrinsic load (characteristics of the material), as this may leave minimal, if any, "room" in working memory for germane load (cognitive activities relevant to learning). Pedagogies that foster germane load, while minimizing extraneous and intrinsic loads, should be more effective for student learning. As such, for student well-being to improve learning, it may act to limit extraneous load and/or maximize germane load.

Cognitive Load Theory Instructional Effects

CLT instructional effects apply the limits of human cognitive architecture and different cognitive loads to demonstrate the effectiveness and efficiency of different instructional or pedagogical methods. The instructional effects are all grounded in empirical evidence and are each briefly outlined in **Table 1** (for a detailed review of each effect see: Sweller et al., 2011).

STUDENT WELL-BEING—A DEFINITION

Research into what constitutes well-being, as well as how well-being can be measured has been growing for over three decades (see: Ryff, 1989; Diener et al., 1999; Keyes, 2002; Seligman, 2011; Huppert and So, 2013;). Historically, two approaches to well-being have emerged (Deci and Ryan, 2008): firstly, the hedonic tradition, initially explored by the Greek philosopher Epicurus who believed that the greatest good was to seek pleasure in the form of a state of tranquility and freedom from fear and absence of bodily pain. According to Epicurus the combination of these two states constitutes happiness in its highest form Rosenbaum (1990). More recently, researchers under the hedonic tradition have explored the constructs of happiness (e.g., Lyubomirsky et al., 2005), satisfaction with life (e.g., Diener et al., 1999), and positive and negative affect (Watson et al., 1988). The second approach to well-being, the eudaimonic tradition emerged from the Greek philosopher Aristotle, who proposed that the best life for a human being is the life of excellence in accordance with reason. For Aristotle, reason is not only theoretical but practical as well. Excellence of character—involving virtue and service to others—enables a person to exercise practical reason or reason relating to action (Lawrence, 1993). Modern researchers under the eudaimonic tradition have focused on psychological functioning (e.g., Ryff and Keyes, 1995; Kashdan and Rottenberg, 2010), strengths and virtues (e.g., Peterson and Seligman, 2004), meaning (e.g., Steger et al., 2006; Wong, 2011), and pro-social behavior (e.g., Froh et al., 2010). Despite these two differing philosophical traditions of well-being, a general consensus amongst scholars and researchers is that well-being is a complex, multi-dimensional *construct* (e.g., Ryff and Keyes, 1995; Diener et al., 2010; Seligman, 2011; Huppert and So, 2013).

Definitions of well-being are prolific within in the positive psychology literature (for review see; Dodge et al., 2012), however, scholars agree that well-being is not just the presence and abundance of positive states, but also the absence, or scarcity, of negative states (Diener et al., 1999, 2010; Keyes, 2005; Seligman, 2011). This review does not attempt to provide an overview of the differing definitions or constructs of well-being but aims to explore the relationship between the different components of well-being and cognitive load. As such a common definition of well-being, that is well-supported within the positive psychology literature is required. Huppert and So (2013) define well-being as *"feeling good and functioning effectively" (p. 838)* offering a simple definition.

The *feeling good* aspect of well-being revolves around the hedonic aspects of well-being, with the balance of positive emotions vs. negative emotions being tipped in the positive emotions favor. *Feeling good* encapsulates the emotional aspects of well-being and is about experiencing more positive emotions than negative emotions. It is not about the absence of negative emotions, rather the balance between positive and negative emotional states. *Functioning effectively* encapsulates much of the eudaimonic aspects of well-being whereby individuals can deal with and respond to the ups and downs of everyday life with meaning and purpose. Being able to identify and productively respond to painful, unpleasant, and unwanted situations or events is a psycho-social component of well-being (Ryff and Keyes, 1995; Ryan and Deci, 2000; Steger, 2013). Dezutter et al. (2014) demonstrated that for emerging adults high in meaning these painful, unpleasant or unwanted situations and events are much easier to get through, allowing individuals to *function effectively*. Huppert and So's "*feeling good and functioning effectively,*" definition of well-being will be adopted as a framework from which to analyse how cognitive load may be impacted by these various aspects of well-being and identify how the *feeling good* and *functioning effectively* components may contribute to cognitive load in different ways.

METHODS

This review explored the CLT instructional effects literature to find how the feeling good and functioning effectively components of well-being interact with cognitive load. A search of the database Scopus was conducted using the key terms; "cognitive load" OR "cognitive load theory" AND ("worked example" OR "worked example effect") OR ("expertise reversal" OR "expertise reversal effect") OR ("modality effect") OR ("redundancy effect") OR ("modality effect" OR "modality principle") OR ("redundancy effect" OR "redundancy principle") OR ("redundancy effect" OR "redundancy principle") OR ("split attention" OR "split-attention") OR ("goal-free" OR "goal free" OR "goal specificity") OR ("transience" OR "transient" OR "transitory") OR ("self explanation" OR "self-explanation") OR ("collective working memory" OR "collective memory") OR ("collective working memory" OR "collective memory") OR ("element interactivity"). The search was restricted to

TABLE 1 | Cognitive load theory instructional effects.

Instructional effect	Description	Key references
Goal-free effect	When a conventional problem with a specific goal is replaced by a problem with a non-specific goal, students demonstrate superior learning outcomes.	Owen and Sweller, 1985 Ayres, 1993
Worked example and problem completion effects	When learners presented with a worked example, or step-by-step solution to a problem, perform better on subsequent test problems than learners solving the equivalent problem without a worked example.	Sweller and Cooper, 1985 Cooper and Sweller, 1987
Split-attention effect	When learners are required to split their attention between two or more sources of information that are separated either spatially or in time, an extraneous cognitive load is produced resulting in reduced learning.	Tarmizi and Sweller, 1988 Ginns, 2006
Modality effect	When a learner is presented with information that engages both the auditory and visual channels within working memory. That is, information is presented in dual-modality (diagrams and spoken text) leading to superior learning than the same information presented through a single mode (e.g., diagram and written text).	Mousavi et al., 1995 Moreno and Mayer, 1999 Reinwein, 2012
Redundancy effect	When multiple sources of information can be understood separately, but are both presented simultaneously (e.g., text is presented both visually and auditory at the same time). This redundant information results in an extraneous cognitive load, leading to lower levels of learning than when the redundant information is removed.	Chandler and Sweller, 1991 Leahy et al., 2003
Expertise reversal effect	When information beneficial to novice learners becomes redundant to more knowledgeable and experienced learners, resulting in less effective or even negative consequences on learning.	Kalyuga et al., 1998, 2003 Kalyuga, 2007
Guidance fading effect	Enhancing learning due to the gradual fading of worked examples instead of the consistent use of worked examples or worked example-problem pairs.	Renkl and Atkinson, 2003
Element interactivity effect	The interactivity, or complexity of the elements of information that are required to understand and solve a problem is what determines the intrinsic cognitive load. High element interactivity leads to a greater intrinsic cognitive load, while low element interactivity leads to lower intrinsic cognitive load. The element interactivity effect deals with the intrinsic cognitive load of a problem, rather than the extraneous cognitive load.	Sweller and Chandler, 1994 Sweller, 2010
Imagination and self-explanation effects	After studying a worked example, learners are encouraged to turn away from the example and imagine the steps involved in solving the problem. This results in the learner processing the procedure in working memory resulting in a greater likelihood of this being transferred into long term memory (and learning).	Cooper et al., 2001 Ginns, 2005
Transient information effect	The loss of learning due to information disappearing before the learner has time to adequately process the information.	Mayer and Chandler, 2001 Moreno, 2007
Collective working memory effect	When individual learners gain higher learning outcomes through collaborative work than when learning alone. In a group learning situation, each individual learner's working memory is shared within the group (that is, working memories are additive).	Kirschner et al., 2009 Kirschner et al., 2011

studies conducted with human participants in any educational sector and yielded 495 hits. One hundred and thirty four duplicates and lecture notes were excluded and the remaining 361 abstracts were reviewed. Seventeen articles or conference papers that mentioned feeling good aspects of well-being (e.g., emotions or pain) or functioning effectively (e.g., resilience, academic buoyancy, cognitive regulation) were accessed and reviewed in full. Once each relevant paper was reviewed, the reference section was also scanned for any possible relevant publications that may have been missed in the search with an additional 10 papers included. A total of 60 CLT papers were included in this review with 27 related to well-being.

DISCUSSION: HOW MIGHT WELL-BEING INTERACT WITH A STUDENT'S COGNITIVE LOAD?

How does well-being interact with and influence the cognitive load placed upon a student's working memory? This question, so far, has not been directly tested; however, a review and synthesis of both the CLT and positive psychology literature offers a theoretical model of how well-being may influence cognitive load. Martin (2016) reviewed how reducing cognitive load can also boost motivation and engagement, outlining that load reduction instruction—instructional practices that reduce cognitive load—assists in promoting the motivation and engagement factors of; self-efficacy, valuing, mastery orientation, planning, and monitoring task management and persistence. The focus of this review was on the factors of motivation and engagement, both of which fall within the *functioning effectively* domain of well-being and offers support for a negative relationship between well-being and cognitive load. While Martin argues that load reduction instruction leads to or promotes engagement and motivation, this review will explore the possibility of well-being influencing cognitive load. That is, we propose the causal arrow is in the other direction with well-being leading to reduced cognitive load. Firstly we will identify how the *feeling good* component of well-being, specifically emotions, influences cognitive load, then we will explore how the *functioning effectively* component of well-being leads to the reduction of cognitive load through academic buoyancy (Martin and Marsh, 2006, 2008) and cognitive regulation, ultimately leading to increased learning.

Effects of Emotions on Cognitive Load

The emotional state of a learner, both prior to and during the learning experience, falls within the *feeling good* domain of well-being. In a theoretical review of neuroscience literature, LeDoux and Brown (2017) proposed a Modified Higher Order Theory of Consciousness suggesting that the brain mechanisms that give rise to conscious emotions are not fundamentally different from those that give rise to cognitions. Emotions and cognitions are both similar in the way they are processed within the systems of the brain, but only differ in the inputs into the cortical based general neural networks of the brain. Hence, both cognition and emotions may influence cognitive load during a learning task.

In a recent review of the literature, Plass and Kalyuga (2019) outline four ways that emotions may influence cognitive load. They firstly describe emotions as extraneous cognitive load, as they compete for the limited resources of working memory. Secondly, emotions may affect intrinsic cognitive load—specifically when emotion regulation forms part of the learning outcome/s. Thirdly, emotions influence motivation, which affects mental effort leading to an influence on germane cognitive load. Finally, Plass and Kayluga suggest that emotions affect memory by broadening or narrowing cognitive resources.

The *Broaden and Build Theory* of positive emotions (Fredrickson, 2001) offers a possible explanation for Plass and Kalyuga's (2019) finding that emotions affect memory by broadening or narrowing cognitive resources. The theory states that the evolutionary adaptive purpose of positive emotions serve a different purpose than negative emotions. Whereas, negative emotions evolved to narrow and focus attention so that humans could safely and efficiently escape dangerous and unwanted experiences (e.g., fear leads to increased blood flow to muscle groups to facilitate escape), positive emotions have evolved to expand and consolidate our resources. The broadening of thought-action repertoires associated with positive emotions suggests that the cognitive load on working memory is reduced due to the *Environmental organization and linking principle,* whereby information stored in long term memory is efficiently recalled and applied to the learning task without creating a load on working memory. Conversely the narrowing of attention associated with negative emotions may limit learning due to an increase in extraneous load. Secondly, the building of cognitive resources associated with positive emotions may ensure that germane load is maximized leading to greater learning for students. The broadening and building of cognitive resources associated with positive emotions is demonstrated in the CLT literature as outlined in the studies below.

Fraser et al. (2012) conducted a simulation based training study with 84 medical students exploring the impact of heightened emotions on learning and cognitive load when attempting to recognize cardiac murmurs. Each participants' emotional state was measured using Feldman Barrett and Russell's (1998) bipolar oppositional descriptors of emotions. Participant's emotions were then categorized as either invigorating or tranquility based upon the clustering of these results. This correlational study found that invigorating emotions were associated with increased cognitive load, while tranquility emotions were associated with decreased cognitive load, suggesting that low activation emotions (tranquility) are related to reduced cognitive load. Fraser et al., measured cognitive load based upon the Paas et al. (1994) subjective measure of mental effort, which only offers a measure of total cognitive load. Therefore, this study does not distinguish whether germane load, intrinsic load or extraneous load are associated with invigorating and tranquility emotions. A second study conducted by Um et al. (2012) explored two conflicting hypotheses; firstly that emotions act as extraneous load during learning and secondly, that emotions act as a facilitator of learning. In this study 118 college students' emotional state was induced—to be either positive or neutral—based upon the happy and neutral emotional states of the self-referencing mood induction procedure developed by Seibert and Ellis (1991). Participants emotional state was induced either before or during a computer-based lesson through the use of films before the lesson or with emojis during the lesson. The lesson covered the topic of "how immunization works." Um et al. uncovered some subtle differences in the impact of positive emotions on cognitive load. They found that positive emotions induced during the learning task decreased the perceived difficulty of the task, suggesting that extraneous load had decreased; however, positive emotions induced before the learning task increased the mental effort participants invested during the task, suggesting that germane load had increased.

A study that, at first, appears to contradict the assumption that negative emotions increase cognitive load (and more specifically extraneous load) was conducted by Pretz et al. (2010). This study explored the effect of mood on implicit learning during grammar and serial reaction time tests. Participants were 107 undergraduate students who had their mood manipulated through the use of photographs and measured using the Positive and Negative Affect Schedule (Watson et al., 1988) prior to completing an artificial grammar task and a serial reaction time task. Negative mood was associated with higher performance in implicit learning, suggesting that extraneous cognitive load was lowered with negative mood. Pretz et al. (2010) explained this result by suggesting that negative mood was associated with rational cognitive style which was also associated with higher performance in the artificial grammar test. An alternative explanation is through the narrowing and focusing of negative emotions/mood (Fredrickson, 2001). A third explanation is tied to Pertz et al.'s use of implicit learning, which could be considered *biologically primary knowledge* as Pretz et al. defined implicit learning as; *learning being unconscious and results in abstract, tacit knowledge about complex or hidden covariations in the environment* (Reber, 1989; Seger, 1994). This definition appears to align more with Geary's *biologically primary knowledge,* and as such does not rely on working memory and therefore does not produce a cognitive load.

One of the few negative emotions that have been explored, in relation to its impact upon working memory, is anxiety. According to Eysenck (1992) anxiety inhibits academic performance because working memory is occupied with worry rather than with task-focused thoughts. From a CLT perspective this suggests that the worry associated with anxiety creates an extraneous load, hence hindering learning. The majority of this research, however, is limited to the mathematics domain—described in the literature as *maths anxiety* (Ashcraft and Krause, 2007). The impact of *maths anxiety* upon learning and performance is generally explained through Attentional Control Theory (Eysenck and Calvo, 1992; Eysenck et al., 2007; Derakshan and Eysenck, 2009) rather than CLT.

A correlational study by Chen and Chang (2009) of 88 university aged students in Taiwan explored the relationship between cognitive load, anxiety (measured as foreign language anxiety), and task performance, finding that students with higher foreign language anxiety also incurred a higher cognitive load while performing an English listening comprehension task. This study provides empirical support for a positive relationship between the emotion of anxiety and cognitive load, suggesting that this higher load is extraneous rather than intrinsic—as participants completed the same learning task, or germane—as task performance was negatively related to anxiety and cognitive load. Huang and Mayer (2016), explored the use of anxiety reducing features for computer based statistics lessons. This study was a randomized control trial with 54 undergraduate university students in the USA. The control group was made up of 28 students who completed a computer based statistical training package, while the treatment group completed the identical computer based statistical training package, but also had two anxiety coping strategies—an anxiety coping message and an anxiety coping strategy of expressive writing—included in the lesson. Outcome measures of mental effort (total cognitive load), motivation, retention, transfer, and practice were all collected. Huang and Mayer found that anxiety reducing features did not reduce mental effort (total cognitive load); however, performance in the retention test immediately after the completion of the training was significantly higher for the treatment group. This suggests that anxiety is not only related to extraneous load as demonstrated by Chen and Chang (2009), but may also play a role in inhibiting information moving into long term memory or disrupt the information store principle.

Taken together it is suggested that positive emotions, such as a happy mood state, prior to a learning task increases germane load, while positive emotions during the learning task appears to assist in reducing the extraneous cognitive load. Negative emotions, especially anxiety, appears to act as an extraneous cognitive load, and may also inhibit the transfer of information into long term memory through the disruption of the information store principle.

Effects of Physical and Psychological Pain on Cognitive Load

The effects of physical pain on cognitive load is an area that is beginning to be explored giving some insight into how the cognitive load instructional effects are influenced, in some cases even reversed, when a learner is experiencing physical pain. Seminowicz and Davis (2007) explored the interaction between physical pain—caused by transcutaneous electrical nerve stimulation—and cognitive load. They found that mild to moderate pain had no effect on cognitive task performance. This study by Seminowicz and Davis (2007) only focused on the impact of mild to moderate physical pain and did not explore social or emotional pain, which is often associated with lower levels of mental health, and higher levels of mental illness (Harris, 2006). Contrary to the findings by Seminowicz and Davis, Smith and Ayres (2014) provided considerable evidence that individual teachers in Australia with persistent pain have impaired cognitive performance on tasks requiring them to retain and transfer new information. This study was conducted using self-report measures of cognitive load and persistent pain. One of the key differences between these two studies is that Seminowicz and Davis (2007) induced pain during the cognitive task, whereas Smith and Ayres (2014) based their study on self-reported measures of persistent pain. Also, Smith and Ayres used more naturally occurring, real pain, while Seminowicz and Davis used induced pain. Smith and Ayres conducted two experiments investigating how individual teachers with persistent pain would respond to instructional materials designed to promote the modality and redundancy effects. The first study (Smith and Ayres, 2014) found that participants with persistent pain had a decrease in performance on a multimedia science based task. In a second study, Smith and Ayres (2016) found that the modality effect was not apparent for people with persistent pain, while the modality effect was apparent in pain free participants. Evidence was also found for a reverse redundancy effect in participants experiencing persistent pain, with participants experiencing persistent pain demonstrating superior performance when presented with redundant learning information. As depression and significant life events can have a negative impact on performance (see Christopher and MacDonald, 2005), this study also controlled for participants' depression, suggesting that these results are due to the impact of persistent pain rather than depression. This research provides evidence of the effects of physical pain on cognitive load, but in turn raises the question, how might social, emotional or psychological pain—caused by discomfort, stress, rumination, anxiety, and negative emotions—impact upon cognitive load?

With the recent development of brain imaging and neuroimaging techniques the correlates of different psychological experiences and activated regions in the brain have become possible to observe and may provide theoretical answers for the above question. A number of meta-analyses have shown that physical pain and psychological pain share similar brain regions (see Mee et al., 2006; Kross et al., 2011; Diener et al., 2012; Mutschler et al., 2012). Kross et al. (2011) conducted a meta-analysis of over 500 published studies comparing the overlap between functional MRI scans between social rejection and physical pain. They found that physical pain and social rejection share the same brain regions with values up to 88%. Mee et al. (2006) in a review of evidence from both fMRI and PET scans provide evidence that psychological pain may contribute to depression and also induced psychological pain such as sadness, social exclusion, and grief share similar brain regions as physical pain. A further meta-analysis conducted by Mutschler et al. (2012) shows that for a person suffering from depression, the emotional pain appears to move into the dorsal insular cortex area of the brain, the site shared with physical pain suggesting that emotional pain physically hurts if one is depressed.

With such a strong positive correlation between the regions of the brain activated by physical pain and the areas of the brain activated by psychological pain (Mee et al., 2006), it can be inferred that students suffering from psychological pain may also experience similar effects on cognitive load as students suffering from persistent physical pain. A major premise of this thesis is that emotions interact with cognitive load—specifically extraneous load.

Academic Buoyancy and Cognitive Load

The *functioning effectively* aspect of well-being, involves how students respond to and deal with life events. This is often referred to as resilience, typically characterized as the ability to over-come chronic, acute or major adversities (for review see; Masten, 2015); however, resilience as a construct is notoriously hard to define and is complex in its social and cultural implications. Martin and Marsh (2006, 2008) offer an alternative operationalized construct of academic buoyancy, defined as, *"students' ability to successfully deal with academic setbacks and challenges typical of the ordinary course of school life"* (2008, pp. 54). Academic buoyancy is a more fitting construct for the context of this review as it relates to adolescent students overcoming the full range of everyday, school related challenges, rather than the relative few who experience extreme cases of adversity (Martin and Marsh, 2006). Academic buoyancy offers a positive psychology perspective on everyday academic resilience. A confirmatory study into the model of academic buoyancy (Martin and Marsh, 2008) illuminates one potential means through which resilience may reduce cognitive load. In a study of 598 students from five Australian high schools in Years 8 and 10, Martin and Marsh (2008) used structural equation modeling across two time points to find, firstly, that academic buoyancy is a valid construct, secondly, anxiety is a salient factor in their model, explaining the bulk of variance in academic buoyancy, beyond other predictor factors. This suggests that anxiety may moderate or even mediate the relationship between academic buoyancy and cognitive load. In other words, anxiety is a large factor in the variance of academic buoyancy and sheds light on how *functioning effectively* may interact with and reduce cognitive load through the presence of academic buoyancy and the reduction of anxiety. Martin et al. (2001) demonstrated that students' anxiety predicted counter-productive strategies to deal with fear of failure, suggesting that anxiety may overload working memory with extraneous cognitive load associated with fear and rumination.

A recent study by Martin and Evans (2018) provides promising support for academic buoyancy reducing cognitive load. Three hundred and ninety two year 9–11 Australian high school students participated in a correlational study aimed to validate the Load Reduction Instruction Scale. This scale assesses five cognitive load reducing instructional principles, outlined by Martin (2016); difficulty reduction, support and scaffolding, practice, feedback, and guided independence. The correlation between academic buoyancy and load reduction instruction measures ranged from $r = 0.43$–0.59, suggesting a moderate to strong positive relationship between instructional practices aimed at reducing cognitive load and academic buoyancy. While these results are correlational and do not show causation, they do provide promise for the *functioning effectively* components of well-being acting to reduce cognitive load.

A second possible means through which the *functioning effectively* aspect of well-being may reduce cognitive load can be explained from a self-regulation perspective. Self-regulation involves two distinct components, *behavior regulation*—suppressing expressive behavior (Prencipe et al., 2011), and *cognitive regulation*—attending to or interpreting emotion-eliciting situations in ways that limit emotional responding (Chevalier et al., 2013).

When students are *functioning effectively*, in the face of adversities they have the ability to cognitively regulate and reappraise any negative emotions that arise from the adversity (Seligman et al., 2009). In contrast, students who are functioning less effectively in the face of adversity allow these negative emotions to influence their behavior and as a result these students rely on regulating their behavior instead of their cognition. In a review of the neuroscientific research into the cognitive control of emotions, Ochsner and Gross (2005) outline the distinction between behavioral and cognitive regulation. To summarize, behavior regulation of negative emotions limits expressive action but does not diminish the unpleasant experience, increases sympathetic nervous system activation, but most importantly, worsens memory. In contrast, cognitive regulation helps to decrease physiological arousal, neutralizes negative experience without impairing memory (Jackson et al., 2000; Gross, 2002). This is further supported by more recent research conducted by Modrek et al. (2017) who conducted a cross sectional study with middle school students from a large Northeast US city. Participants completed an inquiry learning task in the domain of Science. A self-report measure of cognitive regulation, behavior regulation observations by their teacher and state standardized test results for academic achievement were collected during the task. Modrek et al. found that after controlling for gender and bilingualism, cognitive regulation was a more important contributor to learning than behavior regulation. This study suggests that regulating behavior may produce a load on working memory through an extraneous cognitive load, while the ability to cognitively regulate and/or reappraise negative emotions reduces this extraneous load. As a result, it is suggested that, when presented with the same cognitively demanding problem, students with higher levels of resilience/academic buoyancy will have a lower extraneous cognitive load than less resilient/academic buoyant students, due to their ability to cognitively regulate rather than behaviorally regulate their response to any negative emotions. In other words, the behavior component of self-regulation may provide an extraneous load on working memory.

A second premise of this review is that the *functioning effectively* component of well-being also plays a role in minimizing cognitive load for a learner. This occurs through the construct of academic buoyancy in the case of adolescent-aged students, minimizing extraneous load. As Martin and Marsh (2008) note, anxiety may moderate or even mediate the relationship between academic buoyancy and extraneous cognitive load.

CONCLUSION

When a student is presented with a learning task or problem, how does their well-being impact upon the mental effort they expend? This review has explored this overarching question from the CLT and PP literature and demonstrates that the *feeling good* aspect of well-being may assist student learning through (a) positive emotions prior to a learning task increasing germane load, (b) positive emotions during the learning task reducing the extraneous cognitive load, and (c) the reduction in negative emotions, especially anxiety, minimizing extraneous cognitive load, and limiting the inhibition the information store principle. The *functioning effectively* aspect of well-being may lead to a reduction in extraneous load via cognitive regulation—rather than behavioral regulation.

This review offers a synthesis of the CLT literature; however, it does not offer direct empirical support for the interaction between well-being and cognitive load. While Martin and Marsh (2008) have demonstrated a moderate to strong positive relationship between cognitive load reducing instructional strategies and academic buoyancy, this offers promise for well-being being negatively associated with cognitive load. Further research into this relationship and possible interaction is required within the fields of CLT and positive psychology. Future research may provide direct empirical evidence for the cognitive and learning benefits of teaching students the skills of well-being within schools and educational institutions.

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BH conceived of the presented idea and carried out the review. BH, DV-B, and JH contributed to the manuscript. DV-B and JH supervised the project.

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