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Self-efficacy change associated with a cognitive load-based intervention in an undergraduate biology course

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ABSTRACT

Cognitive load theory (CLT) holds that discovery learning and other instructional strategies imposing high levels of extraneous load on novice learners hinder learning. Such learning conditions are also associated with significant drops in persistence, a key measure of motivation. However, research within the CLT framework typically engages motivation as a necessary precursor to learning, rather than as an outcome of instruction. In this study, we examine changes in motivational beliefs as outcomes of learners' cognitive processes through a CLT lens as they engage with instruction. Using a double-blind quasi-experimental design, we manipulate the level of cognitive load imposed on participants through instruction and assess changes in self-efficacy from pre-to post-intervention. In an analysis of data from students enrolled in an undergraduate biology course (n = 2078), students in the treatment condition demonstrated significantly higher performance on end-of-semester lab reports and self-efficacy measures. However, post-instruction self-efficacy was not significantly related to performance, controlling for pre-instruction self-efficacy, gender, and scientific reasoning ability. These findings introduce the possibility that the cognitive load imposed on working memory during instruction may affect motivational beliefs and provides a foundation to further explore connections between historically distinct theoretical frameworks such as CLT and social cognitive theory.

In cognitive load theory (CLT), motivational beliefs are considered primarily to be a precursor, rather than an outcome, of instruction (Moreno & Mayer, 2007). CLT research studies typically assume that sufficient motivation is required for participants to invest the mental effort necessary to meet the cognitive demands of instruction (Kanfer & Ackerman, 1989; van Merriënboer & Sweller, 2005). However, nascent work has begun to consider further the nature of the relationship between learning as a function of CLT-based instructional principles and the role of motivation (e.g., Likourezos & Kalyuga, 2017; Paas, Tuovinen, van Merriënboer, & Darabi, 2005; Schnotz, Fries, & Horz, 2009; van Gog & Rummel, 2010). In these analyses, invested mental effort is considered a nexus between cognitive and motivational perspectives as an index of both imposed cognitive load (assuming motivation sufficient to engage for the duration of the learning task; Paas, 1992) and motivation (Pintrich, 1990; Schunk, Pintrich, & Meece, 1996; Wigfield & Eccles, 2000). For example, the imposition of excessive cognitive load is associated with drops in persistence, which is operationally defined as sustained mental effort until the completion of a goal (Britt, 2005; Lewis, Bishay, McArthur, & Chou, 1993; Paas et al., 2005). However, Schnotz and colleagues speculate that stripping too many interesting-but-extraneous details from instruction may result in learning materials that are "no longer optimally activating from a motivational perspective" (p. 81) and consequently decrease invested effort. We test the hypothesis that efficient management of cognitive load can result in positive shifts in measures of motivational belief. The findings of the study presented here suggest that motivational belief (i.e., self-efficacy) may be a consequence of the cognitive load imposed by instruction, rather than merely a necessary precursor of the decision to invest mental effort.

1. Mental effort in the context of cognitive load theory

From the perspective of cognitive load theory, the major factor influencing an individual's success in learning from instruction is the limited ability of working memory to assimilate and structure target information. Working memory capacity is generally considered to be capable of processing very few pieces of information at a time and of retaining them for less than 20–30 s without rehearsal (Cowan, 2001; van Merriënboer & Sweller, 2005). In that sense, working memory functions as a bottleneck, filtering the information to be encoded in

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long-term memory through attentional, conscious processes in ways that are evolutionarily adaptive for information processing (Sweller, 2004). The availability of relevant and well-structured prior knowledge increases the functional capacity of working memory relative to the task, such that an individual with greater expertise will experience a lower burden on working memory resources than an individual with less expertise (Feldon, 2007; Gobet, 1998; Ericsson & Kintsch, 1995; Sweller, 1994).

The capacity of working memory can be operationally defined by the maximum quantity of new, non-automated information it is capable of processing at a given time. As a corollary, the greater the quantity of non-automated or novel information to be processed (i.e., cognitive load), the greater the requirement to invest mental effort for successful processing (Kalyuga, 2011). When the cognitive load imposed exceeds the working memory capacity of the learner, maximal investment of mental effort on the part of the student will not be sufficient to attain the intended learning or performance outcomes (Paas & van Merriënboer, 1993).

In dealing with difficult tasks, higher degrees of cognitive demand impose higher load and require greater effort. In other words, "mental load is imposed by instructional parameters (e.g., task structure, sequence of information), and mental effort refers to the amount of capacity that is allocated to the instructional demands" (Paas, 1992, p. 429). If cognitive load imposed by instructional material exceeds the level of effort an individual can or does invest, instruction will be less effective than if effort is greater than or equal to the demands imposed by the learning task. Learning tasks that have been practiced consistently require less conscious information processing in working memory due to the development of automated knowledge (i.e., learned, unconscious processing) (Anderson, 1982; Blessing & Anderson, 1996; Clark, 2014) and schema development (van Merriënboer & Sweller, 2005).

1.1. Types of cognitive load

CLT currently identifies three categories of cognitive load that might be imposed on a learner during the learning process: intrinsic, extraneous, and germane (Kalyuga, 2011; van Merriënboer & Ayres, 2005). For effective learning to occur, the sum of these loads must remain smaller than the capacity of the learner's working memory. Therefore, the main objective of CLT has been to derive principles for managing cognitive load during instruction to maximize the efficiency and effectiveness of instruction (Paas, Renkl, & Sweller, 2003; Tuovinen & Paas, 2004).

As originally established by Sweller (1993, 1994), intrinsic cognitive load is a characteristic of the information to be learned itself, independent of the learner. Thus, information that entails more propositions or more interactions among knowledge elements imposes a higher level of intrinsic load by definition (van Merriënboer & Sweller, 2005). More recent studies, however, argue that the level of intrinsic load is also influenced by "the degree of interactivity between essential elements of information relative to the level of learner expertise in the domain" (Kalyuga, 2011, p. 2). As such, an individual with higher levels of relevant and accurate prior knowledge will process information with a lower burden on working memory (i.e. intrinsic cognitive load) than an individual with a lower level of prior knowledge. Further, this approach permits convergence between the intrinsic and germane load constructs, with the total quantity of cognitive load necessary for optimal learning represented by the learner's capacity for processing the instructional content itself combined with the appropriate instructional mechanisms necessary for optimal learning to take place.

Extraneous cognitive load is imposed by burdening working memory during instruction in a manner that does not positively contribute to learning. This type of load is associated with inappropriate instructional design and activities, which can manifest in two possible ways. First, instruction or instructional materials may force a learner to process unnecessary or irrelevant information that results in unproductive element interactivity in working memory (Ayres & Paas, 2012; Kalyuga, Chandler, & Sweller, 1999; Mayer, Heiser, & Lonn, 2001; Sweller, 2010; Sweller, van Merriënboer, & Paas, 1998). Second, information necessary or beneficial to instruction may be withheld, which forces a learner to simultaneously structure and attempt to solve a problem for which appropriate schemas are not yet developed (Likourezos & Kalyuga, 2016; Sweller, 1988). Similarly, "any instructional procedure that requires learners to engage in … a search for referents in an explanation (i.e., when Part A of an explanation refers to Part B without clearly indicating where Part B is to be found) is likely to impose a heavy extraneous cognitive load because working memory resources must be used for activities that are irrelevant to schema acquisition and automation" (Paas et al., 2003, p. 2). Thus, when guidance is needed and not provided, cognitive information processing becomes a burden to learners and likely ineffective for learning (Kirschner, Sweller, & Clark, 2006).

2. Mental effort in the context of motivation theories

Theories of motivation consider investment of mental effort to be one of three major indicators of motivation, along with goal selection (a decision of where to invest mental effort) and persistence (the maintenance of mental effort over time until a goal is achieved) (Pintrich, 1990; Schunk et al., 1996; Wigfield & Eccles, 2000). When motivated, learners also tend to demonstrate a more strategic approach to learning tasks and direct mental effort toward processes that are more pertinent to learning (Rey & Buchwald, 2011).

One of the most prominent theories of motivation that links beliefs to effort investment is social cognitive theory (SCT; Bandura, 1982; 1997). SCT holds that self-efficacy (i.e. one's belief in their capability to manage and succeed in a particular task) drives the investment of mental effort (Bandura, 1982), because "unless people believe that they can produce desired effects by their actions, they have little incentive to act" (Bandura, Barbaranelli, Caprara, & Pastorelli, 1996, p. 1206). Further, successful past performances can enhance self-efficacy, contributing to higher goal aspirations and further investment of effort, which produce subsequent performance improvements (Bandura, 1997). This perspective has driven a large proportion of motivation studies in education, with meta-analyses supporting the positive relationship between self-efficacy and achievement (Bandura & Locke, 2003; Multon, Brown, & Lent, 1991; Stajkovic & Luthans, 1998).

2.1. Anticipated investment of mental effort

From the SCT perspective, learners' beliefs about the necessary level of effort to invest in a learning task is of central importance. Similarly, CLT assumes that in order for instruction to be effective, students need to be motivated so that they will invest sufficient mental effort to meet the cognitive demands imposed by the instruction (van Merriënboer & Sweller, 2005). Such motivation is typically indicated by the learner's choice to engage in a given learning task (i.e. goal selection), so that if the perception of task difficulty is extremely high, it could lead to a lack of engagement (Clark, 1999). Salomon (1984) argued that students "make judgments on the basis of the perceived attributes of the instructional procedures, and subsequently expend mental effort accordingly" (p. 649).

For example, Zheng, McAlack, Wilmes, Kohler-Evans, and Williamson (2009) found that participants receiving instruction within an interactive multimedia context reported greater self-efficacy than their counterparts in a non-interactive version. In this case, the participants' perceptions and expectations regarding instructional format were highly salient, because self-efficacy mediated the relationship between instructional condition and task performance. While the influence of instructional condition on self-efficacy and the influence of self-efficacy on performance were each positive, the direct effect of