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Embedded interruptions and task complexity influence schema-related cognitive load progression in an abstract learning task

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A B S T R A C T

Cognitive processes related to schema acquisition comprise an essential source of demands in learning situations. Since the related amount of cognitive load is supposed to change over time, plausible temporal models of load progression based on different theoretical backgrounds are inspected in this study. A total of 116 student participants completed a basal symbol sequence learning task, which provided insights into underlying cognitive dynamics. Two levels of task complexity were determined by the amount of elements within the symbol sequence. In addition, interruptions due to an embedded secondary task occurred at five predefined stages over the task. Within the resulting 2x5-factorial mixed between-within design, the continuous monitoring of efficiency in learning performance enabled assumptions on relevant resource investment. From the obtained results, a non-linear change of learning efficiency over time seems most plausible in terms of cognitive load progression. Moreover, different effects of the induced interruptions show up in conditions of task complexity, which indicate the activation of distinct cognitive mechanisms related to structural aspects of the task. Findings are discussed in the light of evidence from research on memory and information processing.

1. Introduction

From a cognitive point of view, to inspect learning means to deal with schema acquisition as a relevant outcome. Since learning itself is a process and thus relates to the aspect of time, the need arises to inspect demands resulting from schema acquisition under a temporal perspective. Such has already been outlined by Renkl and Atkinson (2003) and extended in more recent research by Renkl (2014), in which distinct process stages are discussed. However, details on underlying progression models of schema acquisition have not yet been explicitly tested, although such knowledge would especially offer a benefit to multimedia-based learning scenarios. These settings are more prone to overload learners' mental facilities due to the multimodal, interactive and often temporally and spatially distributed presentation of information. Accepting the arising challenge, the research community needs to develop predictive models on opportune stages of task-related cognitive load to adapt instructional situations to learners' cognitive resource supply. The current study takes a step forward in clarifying extant theoretical assumptions on cognitive load by comparing plausible progression models on a statistical base.

A prominent cognitive theory, which provides advice for the conducive design of media-transmitted instructions, is the Cognitive Load Theory (CLT; Sweller, 1988; Sweller, Ayres, & Kalyuga, 2011). It is based on the assumptions of duration and capacity limitations in working memory, a virtually unlimited storage capacity of long-term memory and the representation and organization of knowledge via schemata. Learning performance, at a certain point in time, is impaired if the total amount of processing requirements exceeds the limitations of mental resources. According to previous research, cognitive load in learning situations arises from three different sources, which have to be considered on distinct observational and temporal levels. Firstly, task complexity in relation to learners' previous knowledge constitutes intrinsic cognitive load (ICL) as an inherent characteristic of relevant learning material (Sweller & Chandler, 1994). Secondly, the effects of inappropriate instructional presentation add to extraneous cognitive load (ECL), which is not related to relevant learning content. Both aspects affect performance on a more structural and short-term level. The aspect of ICL is traditionally defined in terms of element interactivity, characterized by the number of logically related information units (e.g., symbols, concepts, procedures), which learners have to process simultaneously in working memory (Sweller, 2010). ICL has been addressed experimentally by Beckmann (2010) and Wirzberger, Beege, Schneider, Nebel, and Rey (2016), who used a priori estimates of task complexity in arbitrary learning material. These estimates were based

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on the number of interrelated dimensions or elements that participants had to deal with at the same time. By contrast, the conceptualization of ECL usually aligns with the violation of recommended multimedia design principles for presenting instructional content (Mayer, 2014; Sweller et al., 2011). Extending that view on the instructional situation as a whole, inappropriate situational constraints, which demand learners' mental resources, should also be taken into account (Wickens, Hollands, Banbury, & Parasuraman, 2013), for instance, when being interrupted during task execution. The arising task-irrelevant information represents a competing goal that detracts learners' cognitive resources from the actual task focus (Gerjets, Scheiter, & Schorr, 2003). In consequence, they might use less demanding but also less effective strategies to reach their learning goals. Thirdly, another source of cognitive load arises from the process of learning itself, specified as schema acquisition and automation within the theoretical framework (Kalyuga, 2010). Both aspects represent the germane cognitive load (GCL) and need to be considered in terms of processual and long-term accounts. This view corresponds to more recent approaches, which assume a dual framework of germane resources dealing with relevant aspects of instructional material and extraneous resources dedicated to handle irrelevant situational characteristics (Kalyuga, 2011; Sweller, 2010; Sweller et al., 2011). The authors postulate a sufficient approach to explain demands on learners' resources without redundancy, as GCL mainly reflects how learners deal with the amount of ICL imposed by a task. On the one hand, such reformulation respects the fact that certain cognitive load factors benefit learning, while on the other hand, it implies a highly motivated learner who is willing to spend all available cognitive resources on relevant aspects of the learning situation. Approaching GCL on a measurement level, changes in learning efficiency can be regarded as valid indicator of changes in the level of imposed load, since with increasing acquisition of knowledge structures the same performance can be achieved with less investment in cognitive resources (Sweller et al., 2011).

As already stated initially, cognitive schemata constitute an essential achievement of learning, since well-established and organized knowledge structures foster a fast and easy information retrieval. This raises the importance of inspecting underlying cognitive processes of schema acquisition in more detail. From a historical perspective, schemata can be described in terms of mental structures or networks of knowledge, stored in the long-term memory, which incorporate general representations of specific information about an individual's world (Bartlett, 1932). The core function consists of forming guidelines for the interpretation, categorization (Beck, 1964) and appropriate response towards any kind of sensory input (Bower, Black, & Turner, 1979; Neuschatz, Lampinen, Preston, Hawkins, & Toglia, 2002; Rumelhart, 1980). Gagné and Dick (1983) emphasize a more active view of schemata in terms of procedural rules related to the process of understanding. Anderson (1984) describes several functions of schemata, allocated to memory encoding on the one hand, and allocated to information retrieval on the other hand. Once established, schemata provide a considerable reduction in time and capacity needed for mental processing (Bransford & Johnson, 1972; Rumelhart & Ortony, 1977), since their use becomes increasingly automated (Shiffrin & Schneider, 1977). However, the use of schemata is prone to errors. In particular, inappropriate prior schematic knowledge can interfere with proper memory recall (Bartlett, 1932; Brewer & Treyens, 1981; Sulin & Dooling, 1974). Regarding structural issues, schemata comprise a set of non-identical units, which are interrelated in terms of shared similarities (Anderson, 1984; Bartlett, 1932; Rumelhart, 1980; Rumelhart & Ortony, 1977). They are usually characterized by chronological (Bartlett, 1932) and hierarchical (Rumelhart & Ortony, 1977) order, with sub-units relating to multiple larger schemata (Head & Holmes, 1911; Rumelhart & Ortony, 1977). Head and Holmes (1911) further postulated the adaptability and modifiability of schemata, meaning that smaller units can be interchanged or broken up. Piaget (1952) identified two mechanisms responsible for such alterations: assimilation incorporates new information into existing schemata when searching for relevant similarities, whereas accommodation expands existing schemata with new elements when detecting relevant differences. In a recent review, Ghosh and Gilboa (2014) summarized the broad historical literature on schemata and derived a set of necessary and additional features of cognitive schemata. Corresponding to the subsequently outlined overview, they emphasized associative network structures, the rest upon multiple episodes, a lack of unit detail and an adaptability to modifications as necessary features. Additional features comprise chronological relationships, hierarchical organization, cross-connectivity and embedded response options.

Referring back to the CLT perspective, as already outlined, constructing and storing schemata in long-term memory during the learning process imposes GCL (van Bruggen, Kirschner, & Jochems, 2002). Relevant cognitive load increases with effort invested in establishing and automating task-related schemata of knowledge (van Merriënboer, Schuurman, De Croock, & Paas, 2002). With increasing element interactivity in learning material and thereby imposed complexity, ICL increases and demands limited working memory capacity, as well as being responsible for keeping schema-relevant information present. As a consequence, with more interconnected elements represented in learning material, higher mental effort is necessary to maintain information and construct schemata. Arising demands can even prevent further construction of schemata, if complexity exceeds learners' available resources (van Bruggen et al., 2002). Already existing schemata can reduce complexity and thus cognitive load, by reducing the amount of information to be maintained in working memory. Moreover, elements stored in long-term memory can facilitate the effectively organized interpretation and storage of sensory input in relation to existing structures (Valcke, 2002). The importance of available schemata has further been shown by Pollock, Chandler, and Sweller (2002), who stated that mental load may impede any kind of learning, if prior knowledge from previously established basic schemata is lacking.

Besides these demands that inherently arise from the used learning material, unrelated situational characteristics can impact learning processes as well. For instance, being interrupted while performing a learning task represents a potential source of ECL, since it usually impairs learning performance and interferes with coherent schema acquisition (Mayer, 2014). According to Brixey et al. (2007), interruptions are defined as unplanned breaks in human activity, which are initiated by internal or external sources in a situated context and result in discontinuities in task performance. Such events are prone to reduce efficiency and productivity and contribute to errors. Related impairing factors as well as potential strategies of prevention have been broadly inspected by various researchers (e.g., Gillie & Broadbent, 1989; Monk, Trafton, & Boehm-Davis, 2008; Trafton, Altmann, Brock, & Mintz, 2003). A commonly used indicator to determine the disruptiveness of an interruption is the time needed to return to the suspended task. Trafton et al. (2003) refer to this period as *resumption lag*, which is usually characterized by an initial decrease in how quickly people can perform the interrupted task. Besides other factors, it is influenced by the duration of the preceding interruption, with increased interference by longer interruption durations (Monk et al., 2008). Referring back to instructional situations, apart from negative effects on learning, resumption performance can hint at the stage of schema acquisition at various points in time. Practically, learners' cognitive resources should be less affected by maintaining interrupted tasks when certain content has already been transferred from temporary working memory structures to more durable long-term memory structures. In this vein, interruptions induced at defined stages during a task can serve as a test of the "robustness" of acquired schemata over time.

Approaching temporal characteristics during schema acquisition in more detail, Leppink and van Merriënboer (2015) already suggested that it would be worthwhile monitoring performance and mental effort