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Effects of pairs of problems and examples on task performance and different types of cognitive load

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ABSTRACT

In two studies, we investigated whether a recently developed psychometric instrument can differentiate intrinsic, extraneous, and germane cognitive load. Study I revealed a similar three-factor solution for language learning ($n = 108$) and a statistics lecture ($n = 174$), and statistics exam scores correlated negatively with the factors assumed to represent intrinsic and extraneous cognitive load during the lecture. In Study II, university freshmen who studied applications of Bayes' theorem in example–example ($n = 18$) or example–problem ($n = 18$) condition demonstrated better posttest performance than their peers who studied the applications in problem–example ($n = 18$) or problem–problem ($n = 20$) condition, and a slightly modified version of the aforementioned psychometric instrument could help researchers to differentiate intrinsic and extraneous cognitive load. The findings provide support for a recent reconceptualization of germane cognitive load as referring to the actual working memory resources devoted to dealing with intrinsic cognitive load.

1. Introduction

The central tenet of cognitive load theory (Sweller, 2010; Sweller, Ayres, & Kalyuga, 2011; Sweller, Van Merriënboer, & Paas, 1998; Van Merriënboer & Sweller, 2005, 2010) is that human cognitive architecture – and especially the limitations of working memory – should be taken into account when designing instruction. Working memory has a limited capacity of seven plus or minus two elements (or chunks) of information when merely holding information (Miller, 1956) and even fewer (circa four) when processing information (Cowan, 2001). Working memory load (or cognitive load) is therefore determined by the number of information elements that need to be processed simultaneously within a certain amount of time (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007). Originally, cognitive load theory distinguished between two sources of cognitive load, namely intrinsic and extraneous cognitive load (Sweller, 2010; Sweller et al., 2011, 1998).

Intrinsic cognitive load is determined by the intrinsic nature of the information to be learned, more specifically, by the number of interacting information elements that the learning task or the learning material comprises (Sweller, 1994; Sweller et al., 2011). Novices, who have little if any prior knowledge of the task or material, have to process (i.e., select, organize, and integrate) those interacting elements in order to learn the task or material. As learning progresses (i.e., expertise increases), information elements become incorporated (or chunked) into cognitive schemata stored in long-term memory, which can be handled as one single element in working memory. Therefore, the intrinsic cognitive load that is imposed by a learning task or learning materials is much higher for novices than for more advanced students.

Extraneous cognitive load arises from suboptimal instructional methods that require the learner to engage in cognitive processes that do not contribute directly to the construction of cognitive schemata (e.g., having to mentally integrate spatially or temporally separated but mutually referring information sources) and are as such unnecessary and extraneous to the learning goals (Sweller & Chandler, 1994; Sweller, Chandler, Tierney, & Cooper, 1990). Such processes can hamper learning if intrinsic cognitive load is high or

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lead to suboptimal learning under conditions in which intrinsic cognitive load is low. That is, even though extraneous cognitive load can be managed without hampering learning under such conditions, a replacement of the extraneous by cognitive load that is directly relevant for learning (i.e., *germane cognitive load*; Sweller et al., 1998) would have resulted in better learning outcomes.

The concept of germane cognitive load was added to the cognitive load framework later on (Sweller et al., 1998). This type of load arises from relating relevant information from long-term memory or context to the new information elements (Sweller, 2010; Sweller et al., 2011) and as such pertains to the working memory resources allocated to dealing with intrinsic cognitive load (Kalyuga, 2011; Sweller, 2010). In fact, the term 'germane cognitive load' has been used in the traditional conceptualization of cognitive load theory (Sweller et al., 1998), while the term 'germane resources' (i.e., working memory resources allocated to dealing with intrinsic cognitive load) has been used in the recent version of the theory and is thus related to intrinsic cognitive load (Kalyuga, 2011; Sweller, 2010; Sweller et al., 2011).

Cognitive load theory states that intrinsic cognitive load should be optimized in instructional design by selecting materials that match the learner's prior knowledge or proficiency, while extraneous cognitive load should be minimized, and learners should be challenged to engage in processes that evoke germane cognitive load (in the old conceptualization of cognitive load theory) or the use of (in the new conceptualization of the theory) germane resources (e.g., variability in practice, elaboration, or self-explanation) and contribute directly to the construction of cognitive schemata (Sweller et al., 1998; Van Merriënboer & Sweller, 2005, 2010). To avoid confusion due to using both terms interchangeably thereby referring to two different conceptualizations of the theory, in the remainder of this paper we use the term 'germane cognitive load' as referring to the use of germane resources, as suggested by Kalyuga (2011), Sweller (2010), and Sweller et al. (2011).

1.1. Instructional guidance and cognitive load

The extent to which instructional features contribute to intrinsic or extraneous cognitive load may depend on the individual learner. For instance, novice learners, for whom information imposes high intrinsic cognitive load, may learn better from an instructional format that reduces extraneous cognitive load, such as worked examples (i.e., fully worked-out problem solutions; Cooper & Sweller, 1987; Paas, 1992; Paas & Van Merriënboer, 1994a; Sweller & Cooper, 1985; Van Gog, Paas, & Van Merriënboer, 2006) or from completing partially worked-out solutions (i.e., completion problems; Paas, 1992; Van Merriënboer, 1990) than from autonomous problem solving. Problem solving imposes high extraneous cognitive load for novice learners, because their lack of prior knowledge of how to solve that type of problem forces them to resort to weak problem-solving strategies. Because (part of) the solution is worked out in worked examples and completion problems, the extraneous cognitive load imposed by the use of weak problem-solving strategies is prevented, and learners can allocate more of their working memory resources to dealing with intrinsic cognitive load (i.e., germane resources).

More knowledgeable learners, on the other hand, benefit optimally from autonomous problem solving, because they have already acquired knowledge of how to solve that type of problem, which can guide their problem solving. Instructional formats that are beneficial for novice learners lose their effectiveness and can even have negative consequences for more knowledgeable learners (i.e., expertise reversal effect; Kalyuga, Ayres, Chandler, & Sweller, 2003; Kalyuga, Chandler, Tuovinen, & Sweller, 2001; Leppink, Broers, Imbos, Van der Vleuten, & Berger, 2012a, 2012b, 2013b). The information presented in worked examples is redundant for more knowledgeable learners, who are able to solve the problem without instructional guidance, and processing redundant information contributes to extraneous cognitive load (i.e., redundancy effect; Chandler & Sweller, 1991).

1.2. Measurement of cognitive load with subjective rating scales

Subjective rating scales like Paas' (1992) nine-point unidimensional mental effort rating scale have been used intensively for measuring the overall cognitive load experienced by learners (for reviews: Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Van Gog & Paas, 2008). Mental effort has been defined by Paas et al., as "the cognitive capacity that is actually allocated to accommodate the demands imposed by the task; thus, it can be considered to reflect the actual cognitive load" (Paas, Tuovinen et al., 2003, p. 64; see also Paas & Van Merriënboer, 1994b). It is not entirely clear to what extent workload and cognitive load refer to the same concept across contexts, but the multidimensional NASA-TLX (Hart & Staveland, 1998) is an example of another instrument that subjectively assesses experienced workload on five seven-point rating scales. Increments of high, medium, and low estimates for each point result in 21 gradations on the scales (Hilbert & Renkl, 2009; Zumbach & Mohraz, 2008).

While measuring overall experienced cognitive load by subjective or objective techniques can be informative – especially in relation to measures of learning outcomes (Van Gog & Paas, 2008) – it is less specific than measurement of different types of cognitive load separately when it comes to informing the design of instruction. Therefore, several studies have attempted to develop instruments for measuring the three types of cognitive load separately (Ayres, 2006; Cierniak, Scheiter, & Gerjets, 2009; De Leeuw & Mayer, 2008; Eysink et al., 2009; Galy, Cariou, & Mélan, 2012). A drawback of those studies is that one or more types of cognitive load were represented by one single item. The use of multiple indicators for each of the separate types of cognitive load might yield a more precise measurement and might enable researchers to separate the types of cognitive load more clearly than the use of a single indicator for each scale. Further, when referring to one very specific instructional feature or cognitive process to measure extraneous cognitive load or germane cognitive load, a conceptual problem may arise, because the expertise reversal effect illustrates that a particular instructional feature may be associated with germane cognitive load for one learner and with extraneous cognitive load for another learner (Kalyuga et al., 2001, 2003).

1.3. A new measurement instrument for distinguishing the three types of cognitive load

Recently, a psychometric instrument was developed that took an alternative approach to the formulation of the questions for measuring different types of cognitive load (Leppink, Paas, Van der Vleuten, Van Gog, & Van Merriënboer, 2013), which may solve the problem of not being able to distinguish between different types of cognitive load at least to a certain extent. If germane cognitive load pertains to the working memory resources allocated to dealing with intrinsic cognitive load, as suggested recently by Sweller (2010) and Kalyuga (2011), it may be difficult to distinguish between germane cognitive load and intrinsic cognitive load. Although this new psychometric instrument (Leppink, Paas et al. 2013) revealed a robust three-factor structure, for a number of reasons it is not yet clear whether these three factors indeed represent the three types of cognitive load.