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Relations between the worked example and generation effects on immediate and delayed tests

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ABSTRACT

The contradiction between the worked example effect that occurs when learners presented with more instructional guidance learn more than learners presented with less guidance and the generation effect that occurs when the reverse result is obtained can be resolved by the suggestion that the worked example effect is obtained using materials high in element interactivity, whereas simpler, low element interactivity materials result in the generation effect. A 2 (guidance: low vs. high) × 2 (element interactivity: low vs. high) × 2 (expertise: low vs. high) experiment investigated this hypothesis with high school trigonometry learners. On an immediate test, high guidance reflecting a worked example effect was found for novices, but a generation effect was obtained for more knowledgeable learners. In contrast, on a delayed test, a three-way interaction between guidance, element interactivity and expertise was found. This interaction was caused by a worked example effect for material high in element interactivity and a generation effect for material low in element interactivity for novices while for more knowledgeable learners, a generation effect was obtained for both low and high element interactivity materials. These results suggest firstly, that both the worked example and generation effects may be more likely on delayed than immediate tests and secondly, that the worked example effect relies on high element interactivity material while the generation effect relies on low element interactivity material.

How much guidance should be provided to facilitate students' learning? On the one hand, within the framework of cognitive load theory, there is evidence that worked examples which provide full problem solving guidance lead to superior performance on subsequent tests of knowledge of solution procedures than actual problem solving with no guidance, demonstrating the worked example effect. On the other hand, there is evidence that requiring students to generate items using, for example, a paired associate paradigm, leads to better memory of the items on subsequent tests than externally presented answers, demonstrating the generation effect.

A possible solution to this contradiction is that these differential results are caused by different levels of element interactivity or complexity of the materials (Chen, Kalyuga, & Sweller, 2015). Problem solving tasks characteristically use complex materials while memorization tasks use much simpler materials. Cognitive load theory provides a definition and measure of complexity of instructional materials via the concept of element interactivity.

1. Cognitive load theory and element interactivity

Cognitive load theory is an instructional theory based on our knowledge of human cognitive architecture (Sweller, Ayres, & Kalyuga, 2011). This architecture constitutes a natural information processing system similar to evolution by natural selection (Sweller & Sweller, 2006) that can be described by five principles.

(a) *Information Store Principle.* In order to function in a complex environment, natural information processing systems must incorporate a large store of information. Long-term memory provides that store in human cognition.
(b) *Borrowing and Reorganizing Principle.* That store of information is largely created by borrowing information from other people by imitation, reading and listening.
(c) *Randomness as Genesis Principle.* When required information is not available from others, it must be created. A random

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generate-and-test procedure during problem solving performs this role in human cognition.

(d) *Narrow Limits of Change Principle.* In order to avoid the need to generate huge numbers of possible moves and to prevent significant, rapid, uncontrollable and therefore damaging changes to long-term memory, the system needs to ensure that only small changes occur at a time. Working memory provides that assurance by its very narrow capacity and duration limits when dealing with novel information from the external environment.

(e) *Environmental Organizing and Linking Principle.* In contrast to its limitations when dealing with novel information from the environment, working memory has no known limits when dealing with organized information held in long-term memory. Activated by external signals, large amounts of information can be retrieved rapidly from long-term memory to working memory allowing appropriate responses to those signals.

Based on this architecture, if the material that learners must process is complex and imposes a heavy working memory load, then it is important that instructional procedures do not unnecessarily add to that load. If the material is simpler and does not impose a heavy working memory load, then factors other than working memory load are likely to determine the effectiveness of instruction and so instructional procedures may not need to take cognitive load into account.

Element interactivity determines the extent to which information imposes a heavy cognitive load due to either its intrinsic characteristics or due to extraneous factors such as the instructional design used (Sweller & Chandler, 1994; Sweller, 2010). It is intended to provide a measure of complexity that takes into account the nature of the learning materials, known as intrinsic cognitive load, the manner in which learners interact with those learning materials, known as extraneous cognitive load, and the learners' knowledge base.

Interactive elements are defined as elements that must be processed simultaneously in working memory in order to complete a task. If those elements are intrinsic to the task at hand, the resultant working memory load is referred to as intrinsic cognitive load. That load can vary from low to high depending on the intrinsic nature of the material being dealt with. For example, when students learn the symbols of the chemical periodic table, each symbol stands for two elements that must be processed in working memory, the symbol and its name. Students can study each symbol individually with no reference to other symbols. When students try to learn the symbol for iron, *Fe*, they can do so independently of learning the symbol for copper, *Cu* and students do not need to pay attention to the relations between them. This kind of material has a low degree of element interactivity and therefore, it has a low intrinsic cognitive load. However, asking students to balance a chemical equation or solve a mathematics problem, such as $ax = b$, *solve for x*, can be high in element interactivity. For the algebra problem, novices need to consider each symbol resulting in 6 elements (including the implied multiplication and the goal symbol) and the relation of each symbol to at least one other symbol, resulting in a minimum of 12 elements that need be processed in working memory simultaneously. This task is relatively high in element interactivity material for novices compared to learning a chemical symbol and so, based on the narrow limits of change principle, imposes a heavy working memory load.

The levels of element interactivity and intrinsic cognitive load are also influenced by the expertise of learners. For an expert faced with the above algebra problem, the environmental organizing and linking principle rather than the narrow limits of change principle comes into play. Because of knowledge held in long-term memory, rather than being faced with 12 or more interacting elements, an expert may be faced with no more than a single element. An expert may immediately recognize the category to which the problem belongs and know the solution. Since the problem and solution consists of a single element, element interactivity is very low with a very low intrinsic cognitive load. Thus, expertise can have a substantial effect on element interactivity and cognitive load.

Extraneous cognitive load also is determined by levels of element interactivity. This load is influenced by the way instructional materials are presented. If element interactivity is altered without altering what needs to be learned, we are dealing with extraneous cognitive load. This load relies entirely on the cognitive activities in which learners must be involved due to the instructional procedures used. The worked example effect provides an example.

2. The worked example effect

This effect occurs if instruction requires learners to solve a problem rather than study a worked example that provides a detailed solution of a problem for a learner to study (Atkinson, Derry, Renkl, & Wortham, 2000; Renkl, 2014; Sweller & Cooper, 1985; Ward & Sweller, 1990). When solving a problem using the randomness as genesis principle, extraneous cognitive load is increased in comparison with studying a worked example using the borrowing and reorganizing principle because more elements must be considered. An unguided problem does not indicate which elements should be attended to while a worked example does, reducing the number of elements that must be processed in working memory. As a consequence, studying worked examples providing instructional guidance is usually superior to problem solving providing no guidance, demonstrating the worked example effect.

Knowledge borrowed from instructors who construct worked examples can be reorganized and transferred to long-term memory for storing, according to the information store principle. Finally, if such knowledge is successfully stored in long-term memory, it can be retrieved when needed to guide activities required for successful functioning in an external environment, according to the environmental organizing and linking principle. Many experiments have repeatedly demonstrated the worked example effect (see Renkl, 2014; Sweller et al., 2011; for recent overviews).

3. The generation effect

The generation effect occurs when items that are generated based on a given stimulus and an encoding rule are better remembered than the same items which are simply read (Slamecka & Graf, 1978). Paired associate lists frequently are used in generation effect studies. For example, one group may be asked to read a paired associate list consisting of words and their opposites (e.g., hot-cold) while the other group may be presented the first word of each pair and told to generate the second word. Tests of memory of the response words characteristically show superiority of the generation group.

Most experiments testing the generation effect have used simple materials that are low in element interactivity. For instance, Pyke and LeFevre (2011) used alphabetic material such as $G + 4 = K$ where "4" refers to the distance between "G" and "K" in the alphabet. The generation group generated each answer while participants in the read group were shown each answer. Both groups then were tested on their knowledge of the distance between letters. Learning this low element interactivity task was superior for the generation group.