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Editorial

Optimising Worked Example Instruction: Different Ways to Increase Germane Cognitive Load

Fred Paas and Tamara van Gog

Educational Technology Expertise Centre,

Open University of the Netherlands, Heerlen, The Netherlands

Author Note:

Correspondence concerning this article should be addressed to Fred Paas, Open University of the Netherlands, Educational Technology Expertise Centre, P.O. Box 2960, 6401 DL, Heerlen, The Netherlands. E-mail: fred.paas@ou.nl.

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Abstract

Worked examples are an effective instructional means to teach complex problem solving skills. It has been argued that worked examples decrease extraneous load, enabling more Working Memory (WM) resources to be directed to activities that facilitate learning and transfer performance. Hence, cognitive load research has started to shift its focus towards finding instructional techniques that impose a germane cognitive load by stimulating the allocation of WM resources to such activities. This special issue provides an overview of recent experimental research on ways to further optimise the design and delivery of worked examples in order to foster learning and transfer.

Optimising Worked Example Instruction: Different Ways to Increase Germane Cognitive Load

According to cognitive load theory (Sweller, 1988; Sweller, Van Merriënboer, & Paas, 1998; Van Merriënboer & Sweller, 2005) complex cognitive tasks contain a high number of interacting elements that have to be processed simultaneously in order to successfully learn to perform such tasks. Given that working memory capacity is considered limited to seven plus or minus two elements or chunks of information (Miller, 1956), tasks that contain a high number of interacting elements that have to be processed in working memory simultaneously, place high demands on working memory. In cognitive load theory, this is referred to as *intrinsic* cognitive load. With increasing expertise, (some of) the elements will become subsumed into a schema, which can be treated as a single element in working memory; hence, the number of interacting elements, and the intrinsic load, decreases. For a long time intrinsic load was considered unalterable by instruction, but recently some techniques were described that seem successful in reducing this load (Gerjets, Scheiter, & Catrambone, 2004, this issue; Pollock, Chandler, & Sweller, 2002), and efforts are being undertaken to measure variations in intrinsic load within a task (Ayres, in press). Next to the load imposed by the task, there is also load imposed by the instructional design. This can take two forms: when it is ineffective for learning, it is called *extraneous* cognitive load; when it is effective for learning it is referred to as *germane* cognitive load (Sweller, 1988; Sweller et al., 1998).

Although extraneous load does not hamper learning when tasks are low in intrinsic load, it does hamper learning when tasks are high in intrinsic load; hence, reducing extraneous load is imperative for such tasks (Van Merriënboer & Sweller, 2005). Research has shown that for tasks high in intrinsic load, problem solving imposes an extraneous load for novice learners (Sweller et al., 1998). Searching for a solution with the weak strategies (e.g., means-ends analysis) that novices often employ, is not as effective for learning as studying worked examples (or worked-out examples as some authors prefer; for overviews of research comparing learning from problem solving with learning from worked examples see Atkinson, Derry, Renkl, & Wortham, 2000). Having learners study worked examples is an effective way to reduce the extraneous load, because the learner can devote all available working memory capacity to studying the worked-out solution and constructing a schema for solving such problems in long-term memory (i.e., learning; Sweller, 1988; 2004).

The surplus cognitive capacity that becomes available by the reduction of extraneous cognitive load can be devoted to activities that further contribute to learning and transfer performance. However, learners are unlikely to engage in such activities spontaneously. Hence, cognitive load research has started to shift attention towards the identification of instructional techniques that stimulate learners to invest cognitive resources in activities relevant for learning, that is, techniques that are successful at inducing germane cognitive load (Paas, Renkl, & Sweller, 2003, 2004; Sweller et al., 1998; Van Merriënboer & Sweller, 2005).

Strategies to Increase Germane Cognitive Load in Learning from Worked Examples

Strategies that are known to increase germane cognitive load induced by worked examples for novice learners, are for example increasing variability (Paas & Van Merriënboer, 1994), or contextual interference (Van Merriënboer, Schuurman, De Croock, & Paas, 2002) in the delivery of worked examples during practice. Prompting students to self-explain the rationale behind worked-out solution steps (Atkinson, Renkl, & Merrill, 2003; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 1997) may also induce a germane cognitive load, provided that learners are capable of providing adequate explanations (see Chi et al., 1989; Renkl, 1997). However, students may lack the prior domain knowledge necessary to do so, especially very early in training, and when this is the case, requiring learners to self-explain is likely to induce an extraneous instead of germane cognitive load (i.e., will be ineffective for learning). In this case, learners may benefit from having the rationale behind solution steps explained in the worked example (see Lovett, 1992). For learners with more prior knowledge, imagining the solution steps can also impose a germane cognitive load, but not for novice learners (Cooper, Tindall-Ford, Chandler, & Sweller, 2001). Thus, considering learners' prior knowledge is important, since it may influence the effectiveness of certain strategies to increase germane load.

Most of those strategies for increasing germane cognitive load in learning from worked examples are effective because they enhance understanding of the solution procedure. That is, they enhance understanding of why solution steps are effective (e.g., self- or instructional explanations of the rationale) and/or of when they should be applied (e.g., variability, contextual interference). That a learner "not only knows the procedural steps for problem-solving tasks, but also understands when to deploy them and why they work" (Gott, Parker Hall, Pokorny, Dibble, & Glaser, 1993, p. 260), is considered imperative for the ability to recognize and flexibly apply the relevant parts of a previously learned procedure to solve novel problems, that is, for attaining transfer (e.g., Catrambone, 1996, 1998; Gott, et al., 1993).

However, in order to be effective, individual learner characteristics and learner motivation need to be considered in applying strategies aimed at inducing a germane cognitive load. As mentioned before, the learning activities that are intended to induce a germane load will only do so unless they are at an appropriate level of difficulty for the learner (e.g., when a learner is capable of self-explaining, instructional explanations are redundant and may impose an extraneous instead of germane load; see also Kalyuga, Ayres, Chandler, & Sweller, 2003) and when learners are willing to actually invest effort in them. As Van Gog, Ericsson, Rikers, and Paas (2005) have noted, this makes the concept of germane cognitive load bear an interesting resemblance to the concept of deliberate practice (Ericsson, Krampe, & Tesch-Römer, 1993).

Measuring Effects of Germane Cognitive Load on Learning

When studying effects of instructional formats on cognitive load, it is important to measure indicators of cognitive load, such as subjective mental effort rating on the 9-point scale developed by Paas (1992), subjective ratings on a modified version of the NASA Task Load Index (see Gerjets, Scheiter, & Catrambone, 2004, this issue), secondary task performance, or physical measures (for a discussion of different measurement techniques see Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

For drawing conclusions on the type of cognitive load imposed by a certain instructional format for a certain learner, however, cognitive load measurements during the learning phase are not informative without learning outcome measurements. For example, two learners (A, and B) have learned the same task, but with two different instructional formats; format A (studied by learner A) was hypothesized to reduce extraneous load, and format B (studied by learner B) to reduce extraneous and increase germane cognitive load. For simplicity, we will assume that they have exactly the same prior knowledge, so that the intrinsic load imposed by the task will be the same (note though, that when this assumption cannot be made, this would further complicate the matter). Learner A has a mean mental effort rating of 6 on the 9-point scale (Paas, 1992) after the learning task, learner B a mean rating of 8. This seems in line with our expectations, however, the conclusion that the effort invested by learner B is indeed indicative of germane cognitive load can only be drawn when this effort indeed contributed to learning (i.e., when the learning outcomes of learner B were higher than those of learner A).

In turn, in those learning outcome measurements, measures of cognitive load should also be taken and considered. A performance score on a test does not provide any information about the costs at which this performance was attained. Since, for example, more automated schemata require less effort to execute, taking both performance and mental effort into account will provide more information about the quality of learning that has taken place than performance measures alone. One can look at performance scores and invested mental effort in the test tasks separately, but one can also combine those measures in one “efficiency measure” (Paas & Van Merriënboer, 1993). Either way, taking into account both measures gives a better indication of the quality of the cognitive schemata participants have acquired than performance scores alone

Note that one should be careful not to confuse this original definition of efficiency (Paas & Van Merriënboer, 1993) with the way it has become adopted and adapted in a large number of studies (see Tuovinen & Paas, 2004, for an overview). The original definition is based on a combination of *test* performance and mental effort invested in the *test*, whereas the adapted definition is based on a combination of *test* performance and mental effort invested in the *training*. This adapted measure may provide interesting information for educational practice, for example, when two instructional formats lead to equal test outcomes, but the first requires learners to invest more effort during training than the second, then the second seems more advisable for practical implementation. However, it also goes here that conclusions on test outcomes should not be drawn solely based on performance scores; hence, it would be better if this adapted formula also included mental effort invested in the test, resulting in a three-dimensional measure (see Tuovinen & Paas, 2004). Furthermore, combining test performance with mental effort invested in the training is especially tricky when the aim is to compare instructional formats that only reduce extraneous load to formats that will also increase germane load. The latter format would by definition be expected to require learners to invest more effort during training, and would hence be expected to result in *less* efficiency, which makes this adapted measure not very informative. Hence, we would recommend researchers interested in measuring germane load effects to not use the adapted efficiency formula, but the one originally proposed by Paas and Van Merriënboer (1993).

Overview of the Articles

The papers collected in this special issue were presented in a symposium at the 11th conference of the European Association for Research on Learning and Instruction (EARLI 2005) in Nicosia, Cyprus. Together, they provide an overview of recent experimental research on possible ways to increase germane cognitive load through interventions aimed at intra- (design) and inter- (delivery/sequencing) worked example features.

To start with the latter, interventions on inter-example features, Reisslein, Atkinson, Seeling, and Reisslein (this issue) studied whether delivering worked examples in problem-example pairs, example-problem pairs, or via a fading strategy would enhance learning for learners with higher and lower prior knowledge. Große and Renkl (this issue) investigated whether the effects of confronting learners with multiple solution methods in worked example pairs (e.g., a tree diagram solution in the first example and an arithmetical solution in the second, equivalent example) combined with either no other intervention, instructional explanations, or self-explanation prompts would positively affect learning. In a second experiment they studied whether varying the representation of multiple solution methods would have further beneficial effects.

The studies that investigate intra-example feature interventions mostly address the effectiveness of different types or quantities of instructional explanations. Gerjets, Scheiter, and Catrambone (this issue) studied in two experiments whether instructional explanations of three levels of elaboration or self-explanation prompts would further enhance learning in combination with two different types of worked examples (molar and modular). Catrambone and Yuasa (this issue) addressed the question of whether elaborations of conditions for executing actions versus elaborations of the *connection* between conditions and actions would enhance learning in combination with "active" (structured exercises) or "passive" (examples) learning. Van Gog, Paas, and Van Merriënboer (this issue) investigated the assumption that adding problem-solving process information, in the form of domain-principled explanations for solution steps and a systematic approach to problem-solving, to worked examples would further enhance learning, whereas providing such information with conventional problems would not be effective. In their commentaries Moreno (this issue) and Sweller (this issue) provide insightful discussions of each of the articles as well as of the overarching theme of this special issue.

The articles in this special issue clearly extend the conventional research on worked example effects by studying a set of innovative instructional methods that build on current cognitive load research developments on the optimisation of cognitive load. More specifically, the methods try to reduce extraneous (and intrinsic) load to enable learners to allocate more cognitive resources to germane cognitive activities. Although the results of the different studies do not provide conclusive evidence for the instructional effectiveness in terms of learning outcomes, they can be considered indicative for how future cognitive load research should proceed.

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