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The double-edged effects of explanation prompts

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ABSTRACT

Explanation prompts usually foster conceptual understanding. However, it has been claimed within cognitive load theory that prompts can take cognitive load to the upper limit when learning complex contents. Under such circumstances, prompts focusing the learners' attention on specific aspects (e.g., conceptual aspects such as elaborations on domain principles) might have some costs: Other important aspects (e.g., procedural aspects such as how to calculate) cannot be processed deeply. Thus, we expected that conceptually-oriented explanation prompts would foster the detailedness of explanations, the number of elaborations on domain principles, and conceptual knowledge. In addition, we tested the influence of such prompts on the number of calculations performed during learning and procedural knowledge. We conducted an experiment in which we employed conceptually-oriented explanation prompts in a complex e-learning module on tax law. Tax law university students ($N = 40$) worked on this e-learning module under two conditions: (a) conceptually-oriented explanation prompts, (b) no prompts. The prompts led to double-edged effects: positive effects on the detailedness of explanations and on the number of elaborations on domain principles, as well as on conceptual knowledge and simultaneously negative effects on the number of calculations performed during learning as well as on procedural knowledge.
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1. Introduction

Explanation prompts are a promising instructional support feature. They induce active processing that the learners are, in principle capable of, but do not spontaneously demonstrate or demonstrate to an unsatisfactory degree (Pressley et al., 1992). Seminal research on explanation prompts revealed that generating a large number of explanations facilitated learning, that is, the greater the number of explanations, the better the students' conceptual understanding (Chi, 2000; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, De Leeuw, Chiu, & LaVancher, 1994; King, 1990; Pressley et al., 1992; Roy & Chi, 2005). Thus, a high detailedness of explanations fostered conceptual understanding. A high detailedness of explanations can be related to the active processing stance that is characterized as a constructivist position because it assumes that knowledge cannot be imparted to the learners but has to be actively constructed by information processing in the working memory (see Robins & Mayer, 1993). However, according to Renkl and Atkinson (2007), the active processing stance does not explicitly specify that it is crucial that the learners' active processing is related not only to the learning contents but to the central domain concepts and principles to be learned (e.g., mathematical theorems, physics laws, tax laws, etc.). Unfocused processing of every detail of the learning material may cost time. Thus, Renkl and Atkinson (2007) proposed a differentiated version of the active processing stance: the focused processing stance. The focused processing stance suggests that the learners should focus on the central domain concepts and principles to be learned. This is especially important because learners often show a performance orientation (Dweck & Leggett, 1988) and mainly focus on how to find the correct solutions to learning tasks. Therefore, they neglect conceptual understanding of central concepts and principles as well as their interrelations.

Against this background, Berthold, Eysink, and Renkl (2009) developed explanation prompts that induced focused processing of conceptual aspects in the domain of probability (e.g., Why do you calculate the total acceptable outcomes by multiplying?). The prompts did not touch procedural aspects. Therefore, we call the prompts conceptually-oriented explanation prompts. In an experiment with psychology students these prompts actually fostered explanations that not only relate solution steps to underlying principles but also explicate the rationale of the respective principle. With respect to learning outcomes, the explanations prompts fostered conceptual knowledge. In the study of Berthold et al. (2009), conceptual knowledge referred to knowledge about the rationale of a solution procedure, that is, why a solution procedure is applied in this way. Conceptual knowledge was assessed, for

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example, by asking the learners to explain why the multiplication rule has to be applied (e.g., "Why are the two fractions multiplied?"). In addition, the prompts enhanced problem-solving performance (i.e., procedural knowledge). Problem-solving performance in probability theory was assessed, for example, by the following item: "Bicycle numberlocks usually have four digits. What is the probability that one guesses the right digit sequence on the first guess?" It is remarkable that the conceptually-oriented explanation prompts that did not touch procedural aspects also fostered problem-solving performance (i.e., procedural knowledge). A more profound conceptual understanding likely supported the learners in their problem-solving efforts.

Evidently, the psychology students who had high prior knowledge in probability theory had enough cognitive capacity to concentrate not only on the prompts-induced conceptual aspects but simultaneously on problem-solving (for the relevance of prior knowledge with respect to the effectiveness of instructional measures see also Wetzels, Kester, & van Merriënboer, 2011, and for the importance of prior knowledge in learning effectiveness see also Mihalca, Salden, Corbalan, Paas, & Miclea, 2011). In contrast to the positive prompt effects on conceptual knowledge and problem-solving, it has recently been claimed within cognitive load theory that prompts may take cognitive load to the upper limit of working memory capacities when learning with complex learning materials (e.g., Sweller, 2006). For example, Gerjets, Scheiter, and Catrambone (2006) looked at the effects of explanation prompts when learning either with "molar" worked solutions (i.e., including "holistic" formulas) or "modular" worked solutions (i.e., composed of a number of separate units that can be considered in isolation) in the domain of probability. The explanation prompts had a detrimental effect on procedural knowledge when learning with modular examples; conceptual knowledge was not tested in this experiment. Große and Renkl (2006) tested to what extent the presentation of multi-representational solutions (i.e., arithmetical equation and pictorial tree diagram) for combinatorics problems enhanced conceptual understanding as compared to the presentation of mono-representational solutions (i.e., arithmetical equation or pictorial tree diagram). In addition, they analyzed the extent to which learning was fostered either by the provision of instructional explanations or by explanation prompts. Multi-representational solutions fostered conceptual knowledge and procedural knowledge. Instructional explanations were superior to open self-explanation prompts with respect to conceptual understanding when learning with multi-representational solutions. Self-explanation prompts had a detrimental effect with respect to conceptual understanding when learning with multi-representational solutions. In the light of these findings, Große and Renkl (2006) suggested that, in the case of complex learning materials, "enriching" worked examples with explanation prompts intended to foster germane load may have negative effects.

With reference to the results of Große and Renkl (2006), Sweller (2006) suggested that it might be necessary to reconsider the advisability of encouraging learners to engage in additional activities while studying materials in complex learning contents. Similarly, Kalyuga (2010) argued that when the instructional material is very complex (i.e., characterized by high degree of element interactivity relative to the learner's level of expertise) it might require heavy intrinsic load to comprehend the instruction. In this case, the available cognitive resources may not be sufficient for sustaining germane activities. Thus, instructional designers must consider that in the case of heavy intrinsic load, instructional procedures designed for fostering productive learning activities (i.e., germane load activities) may lead to very high demands on working memory (see also Schwamborn, Thillmann, Opfermann, & Leutner, 2011). For example, when learners are required to explicitly respond to explanation prompts while studying material that is complex in relation to their prior knowledge, their cognitive capacities can get overwhelmed and learning is unlikely to be effective.

2. Overview of the experiment, hypotheses, and research questions

On the one hand, conceptually-oriented explanation prompts are a promising instructional support feature to foster conceptual understanding. On the other hand, prompts may take cognitive load to the upper limit of working memory capacities when learning with complex learning materials. Under such circumstances, prompts focusing the learners' attention on specific aspects such as conceptual aspects might have some costs: other important aspects such as procedural aspects cannot be processed deeply. Thus, the question arises as to whether conceptually-oriented explanation prompts can facilitate deep conceptual understanding and, simultaneously, foster procedural knowledge.

In this contribution, we present an experiment employing conceptually-oriented explanation prompts in a complex e-learning module in the domain of tax law. The conceptually-oriented explanation prompts were constructed to induce focused processing of the central domain principles included in instructional explanations. We tested the effects of the prompts on learning outcomes, that is, conceptual knowledge (knowledge about concepts and principles that apply within a domain) and procedural knowledge (problem-solving performance) (see De Jong & Ferguson-Hessler, 1996). In addition, we analyzed the effects of the prompts on learning processes, that is, detailedness of explanations during learning and number of elaborations on domain principles during learning as well as number of calculations performed during learning in the prompts responses and annotations. The detailedness of explanations during learning referred to the number of words the learners wrote down on sheets of papers during working on the e-learning module. In the light of the seminal research on explanation prompts that showed that generating a large number of explanations facilitated conceptual understanding (Chi, 2000; Chi et al., 1994; Chi et al., 1989; King, 1990; Pressley et al., 1992; Roy & Chi, 2005), a higher detailedness of explanations during learning can be expected to be helpful for acquiring conceptual knowledge. The number of elaborations on domain principles during learning referred to prompts responses or annotations in the text boxes that elaborate on tax law principles. A higher number of elaborations on domain principles during learning should be positively related to conceptual knowledge because these explanations are expected to foster a principle-based understanding of central principles of the domain (see Renkl, 2005). This category corresponds to Chi et al.'s (1989) category of references to Newton's laws (the underlying domain principles in that study). The number of calculations performed during learning referred to tax law calculations that were performed in the responses and annotations respectively. A higher number of calculations performed during learning can be expected to be positively related to procedural knowledge.

Specifically, we addressed the following hypotheses:

1. Conceptually-oriented explanation prompts foster conceptual knowledge.
2. Conceptually-oriented explanation prompts foster the detailedness of explanations during learning.
3. Conceptually-oriented explanation prompts increase the number of elaborations on domain principles during learning.

In addition, we address the following research questions for which – against the inconsistent empirical background – different expectations can be held. On the one hand, in Berthold et al.'s (2009) study conceptually-oriented explanation prompts fostered not

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