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Inventing a solution and studying a worked solution prepare differently for learning from direct instruction

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A B S T R A C T

Solving an open problem as proposed by inventing and productive failure approaches has been shown to prepare learners effectively for subsequent direct instruction. Inventing can raise awareness of knowledge gaps (cognitive) as well as increase curiosity about and interest in the learning contents (motivational effects). However, studying the problem with a worked solution can have different cognitive and motivational advantages. In two experiments in quite different domains and settings ($N_1 = 42$; $N_2 = 40$), we tested to what extent working on an open problem (inventing)—as opposed to studying a worked solution of the same problem—better prepares (1) student teachers for learning-strategy evaluation, and (2) 8th-graders for learning about ratios in physics. Transfer was better supported by a worked solution. Mediators were the (self-regulated) learning time on most relevant learning contents (Experiment 1) and self-efficacy (Experiment 2). Inventing, however, increased knowledge-gap experience as well as (in Experiment 1) interest and curiosity. The stable transfer effect in two different domains and settings raises interesting questions for further research that had not been systematically investigated so far.

1. Introduction

In order to prepare learners for a new topic and to raise both their attention and curiosity, teachers often start by posing interesting problems before directly instructing learners about the topic. There are similar, experimentally tried-and-tested problem-oriented approaches (Schmidt, DeVolder, DeGrave, Moust, & Patel, 1989) such as inventing problem solutions (Schwartz, Chase, Oppezzo, & Chin, 2011; Schwartz & Martin, 2004) or productive failure at initial problems (Kapur, 2010, 2014). These approaches aim at preparing learners for subsequent direct instruction on canonical solution procedures and concepts by letting students engage in a (brief) inquiry-learning phase about those procedures or concepts (i.e., preparation for future learning, Schwartz & Martin, 2004). Hereby, the students typically invent, discuss, and evaluate solutions to open problems by using contrasting cases. Contrasting cases let important aspects stand out. Given these approaches, should a teacher actually pose such open initial problems for "inventing" or "productive failure" before providing direct instruction? Or can it also be productive to use the cases in a way that resembles tried-and-tested forms of direct instruction such as worked examples (e.g., Renkl, 2014) in order to avoid potential disadvantages of inventing, such as spending extra time when students search for hard-to-find problem solutions (see Sweller, Kirschner, & Clark, 2007)?

However, when immediately starting with methods of direct instruction, a problem might occur: Learners often only superficially process directly presented information (Berthold & Renkl, 2010), which results in little knowledge acquisition and transfer. Problem-oriented introductions such as invention activities can prepare learners for a more in-depth processing of subsequent, directly presented information (see also Lee & Anderson, 2013). For example, Schwartz and Martin (2004) had learners invent formulas describing four different distributions of pitches around a target. Later, the learners were taught the concept of mean deviation. Schwartz and Martin assumed that inventing creates preparedness for future learning by generating "early forms of knowledge" (p. 132, also cf. Lorch et al., 2010). These early forms of knowledge can then be used to easily assimilate further knowledge.

Invention activities can appear to be problematic because learners might not generate canonical or could even generate false

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solutions. According to the IKEA effect—the increased valuation of self-made products (Norton, Mochon, & Ariely, 2012)—, these self-generated, suboptimal solutions can be valued more highly than the expert ones. A similar outcome can be expected when considering the continued-influence effect (Johnson & Seifert, 1994): Learners tend to stick to their own suboptimal solution instead of adopting the directly instructed canonical one. Similarly, Siler, Klahr, and Price (2013) found that students who applied the suboptimal engineering approach instead of the canonical science approach to designing experiments did not benefit from the preparation phase. However, research on productive failure (e.g., Kapur, 2010, 2012; Kapur & Bielaczyc, 2012; Loibl & Rummel, 2014a) shows that initial problem-solving activities can be effective even though invented solutions to problems are often suboptimal or even false (see Schmidt et al., 1989 for similar findings). In addition, larger numbers of suboptimal solution representations were followed by higher learning outcomes (Kapur, 2012, 2014). Difficulties as well as suboptimal solutions can be seen as productive because they cause impasses, making the learners realize that certain solutions do not work in all cases (also see Oser, Näpflin, Hofer, & Aerni, 2012). Furthermore, research on impasse-driven learning has shown that instructional explanations are more effective when given in the context of such an impasse (Sánchez, García-Rodicio, & Acuña, 2009; VanLehn, Siler, Murray, Yamauchi, & Baggett, 2003). If prior knowledge is not sufficient to solve the inventing task and if an impasse is reached, a perceived “vacuum” can help see more clearly the “information needs” and “knowledge gaps to be filled”, which can lead to a better focus on the most relevant contents in a subsequent learning phase (Renkl, 2015). We see the perception of knowledge gaps as a (meta-)cognitive effect and the creation of early forms of prior knowledge as a cognitive effect.

Besides the cognitive effects, problem-oriented instruction can affect motivational states, for example epistemic curiosity—that is, motivation to strive for knowledge—and situational interest. We define epistemic curiosity and situational interest as states that are externally triggered by features of an intervention (Hidi & Berndorff, 1998) *during* learning; note that we do not refer to learners' traits or habitual orientations. Situational interest is a response to a topic or material that is useful to the learner (value-related interest) or induces positive feelings such as ‘feeling stimulated’ (feeling-related interest, Schiefele, 1991). The topic- and material-related situational interest can be a source of intrinsic motivation (Schiefele, 1991) and foster the development of enduring individual interest (Hidi & Renninger, 2006). Epistemic curiosity as a state is a response to particular epistemic stimuli involving qualities of novelty and complexity (Naylor, 1981). An inventing task with contrasting concrete cases from a learning domain potentially seems more complex, novel, and stimulating to a learner than a worked-out problem. Enhancing motivational states can foster deep processing, understanding, and transfer (Belenky & Nokes-Malach, 2012; Entwistle & Ramsden, 1983; Pintrich, 2000; Pugh & Bergin, 2006). Schmidt et al. (1989) discussed epistemic curiosity as an explanatory variable for higher learning outcomes in the problem-based condition of their experiment. Situational interest can be increased because “people like to produce things” (Schwartz & Martin, 2004, p. 171; diSessa, Hammer, Sherin, & Kolpakowski, 1991; Lepper, 1988; Norman & Schmidt, 1992). Situational interest can also be increased when learners perceive knowledge gaps (Rotgans & Schmidt, 2014). Enhancing learners' motivation is argued to be a major advantage of problem-oriented learning in general, but there is little research addressing the question of whether the effects of problem-oriented learning are mediated by motivational factors (Hmelo-Silver, 2004). Most studies do not assess learners' perceived knowledge gaps as a meta-cognitive effect of problem-oriented learning, either.

Some researchers criticize such forms of problem-oriented learning (Mayer, 2004). Sweller et al. (2007) as well as Kirschner, Sweller, and Clark (2006) assume that the problem-oriented activities and especially failure within them are unproductive. “Not only is unguided instruction normally less effective; there is also evidence that it may have negative results when learners acquire misconceptions or incomplete or disorganized knowledge” (Kirschner et al., 2006, p. 84). They criticize that many studies favoring problem-oriented learning did not employ an adequately “strong” comparison group. Such a comparison group has to engage in the same topic and for the same time span as the experimental group, while only varying one ingredient of the instructional activity (see Sweller et al., 2007).

The one ingredient of the instructional activity that stands out from the discussed literature and is still to be tested in more controlled experiments is the amount of generation (Hsu, Kalyuga, & Sweller, 2014): Is a rule, procedure or index generated (invented) or is it given during the preparation activity? The effectiveness of one ingredient of the instructional activity is well documented: Most inventing studies use carefully designed *contrasting cases* (e.g., Roll, Holmes, Day, & Bonn, 2012; Schwartz et al., 2011; Schwartz & Martin, 2004; Wiedmann, Leach, Rummel, & Wiley, 2012). Just like sampling wine side-by-side, contrasting cases can facilitate noticing differences. If carefully designed, learners can notice critical features. For example, when student teachers learn about students' strategy use, they can study contrasting (high-school) student cases. The strategy cases can differ systematically in how well strategies are applied so that evaluation criteria can be invented by contrasting and comparing these cases. Schwartz et al. (2011) found advantages of an inventing condition with contrasting cases (in the domain of physics) as compared to a tell-and-practice condition. Both conditions worked with the same contrasting cases, but in process analyses, they found that the tell-and-practice condition did not contrast the cases but rather worked through them serially. Thus, contrasting the cases is crucial for noticing and learning the deep structure. If people do not learn the deep structure, they rarely exhibit spontaneous transfer to problem isomorphs with differing surface features (Chi & VanLehn, 2012; Gick & Holyoak, 1983). So the question arises if an inventing effect can still be found if the comparison condition also includes the contrasting activities, that is, if the two conditions (an inventing and a comparison) just differ in whether or not an index or criteria is generated or directly presented. Direct instruction with cases (i.e., worked examples) can be implemented in a way that encourages contrasting the cases, too (e.g., by simply providing explanations about the contrasts or prompts in order to compare the cases; e.g., Rittle-Johnson & Star, 2009; see also Renkl, 2014). Is there a benefit in generating a solution to a contrasting-cases problem (inventing) as compared to not generating but processing a given solution to the same problem?

1.1. The present studies

In the present two experiments, we pursued to engage both experimental groups in the same topic for the same time span, while only varying one ingredient of the preparation activity (cf. Sweller et al., 2007). We used a setting in a domain not commonly used in inventing research and a tried and tested inventing domain in order to test whether the basic effect on learning outcomes (i.e., transfer) remains stable.

In the present studies, we aimed at keeping constant the learning activity of contrasting the cases, but varied if the solution to the problem was provided (worked) or generated (invented). In