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Self-regulated learning of principle-based concepts: Do students prefer worked examples, faded examples, or problem solving?

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ABSTRACT

Acquisition of principle-based concepts involves learning how and when to apply a specific principle to different instances of the same problem type. Within this domain, learning is best achieved when practice involves studying worked examples followed by problem solving. When given the choice to use worked examples versus problem solving, how do people regulate their learning? Furthermore, do they use faded examples effectively when given the opportunity during learning? In three experiments, participants learned how to solve probability problems under practice conditions involving either (a) a combined schedule of worked examples, partial examples (Experiments 2 and 3), and problem solving, (b) problem solving only, or (c) self-regulated learning in which participants could choose a worked example, a partial example (Experiments 2 and 3), or problem solving on each trial. Self-regulated learners chose to study worked examples on fewer than 40% of the trials and seldom did so prior to problem solving. However, participants did regulate their learning effectively when they could use partial examples during practice. Participants also demonstrated some sophisticated problem solving, such as by studying worked examples more often after failed versus successful problem-solving attempts.

1. Introduction

Many academic domains involve learning principle-based concepts. A *principle-based concept* (henceforth, "principle" for brevity) typically requires the use of a formula or algorithm for solving a specific type of problem. Once the principle is known, it can be applied to new instances of the same problem type. For instance, if students know the Pythagorean Theorem, they can use it to calculate the length of sides of a right triangle of any size. Principles comprise a core part of foundational knowledge in many academic domains, including physics, engineering, chemistry, math, and computer programming. Because acquisition of principles depends in part on students' learning and practice on their own outside of class, students' success will rely on how well they regulate their learning of these principles. However, little is known about how effectively students use strategies—such as studying worked examples and solving problems—when learning the principles. Accordingly, in the current research, we investigated how students use different strategies to learn principles in a math domain.

When learning principles, two primary strategies available to students include (a) studying an example problem in which each step is worked out and presented alongside the solution (referred to as a *worked example,* Sweller & Cooper, 1985; Cooper & Sweller, 1987; Sweller, 1988) and (b) attempting to solve a problem from start to finish with no support (referred to as *problem solving*). As described further below, these two strategies are differentially effective, and hence investigating how students control their use of them has important implications for enhancing student learning. This issue may be particularly important due to the growing use of automated tutors for instruction in educational settings, particularly systems that require self-regulation. For example, learning of principles in the Assessment and Learning in Knowledge Spaces (ALEKS) system, used widely to support learning of mathematics for grades K-12 and college-level courses (http://www.aleks.com), is almost entirely student regulated. ALEKS does not prescribe how students should learn different principles, but merely provides students with two choices during each learning trial for a given principle: study a worked example or try to solve the problem alone. Thus, the efficacy of such learning technologies may be improved by investigating how students control their learning of principles. Moreover, if students do not use the strategies effectively, they may require training or strategy scaffolds to regulate their studying effectively, regardless of whether they must regulate all of their learning or are being supported by technology (e.g., see Greene, Dellinger, Tüysüzoğlu, & Costa, 2013; Renkl, Berthold, Groβe, & Schwonke, 2013).

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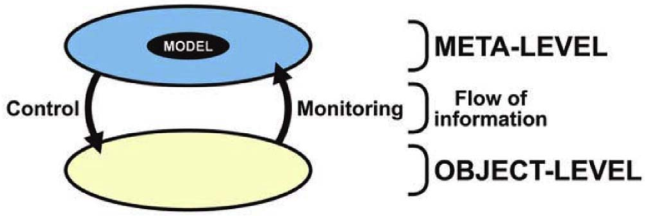

Fig. 1. Meta-level and object-level form a dominance relation that gives rise to monitoring and control processes. The meta-level includes a model of the on-gong task. See text for details. Adapted from Nelson and Narens (1990).

1.1. Frameworks of self-regulated learning

In the present studies, a self-regulated learning (SRL) framework will be used to develop expectations for how students will use worked examples and problem solving when learning principles. Cognitive frameworks of SRL are founded on the relationship between metacognitive monitoring and control processes (e.g., Dunlosky & Ariel, 2011; Winne & Hadwin, 1998). As discussed in detail by Nelson and Narens (1990; 1994), monitoring and control processes arise from the interplay between a meta-level and an object-level system (Nelson & Narens, 1990). The object level system refers to the underlying cognitive processes and structures, such as perceiving and interpreting stimuli within a limited-capacity memory system. As illustrated in Fig. 1, the meta-level system consists of cognitions about the object-level system that pertain either to monitoring information from the object-level or attempting to control on-going object-level processing. One assumption of this framework is that monitoring is used to infer the current level of progress so as to control object-level processing. In the context of the current studies, a student may monitor that a particular problem is taking a long time to solve and infer that she is not making sufficient progress; if so, she may control subsequent processing by changing strategies, such as by studying a worked example instead of attempting to solve another problem.

Hypotheses about how students will self regulate their learning are generated by an understanding of the meta-level monitoring and control processes, whereas hypotheses about how different factors will influence the object-level are generated from theories of the underlying cognitive processes and their interactions. Accordingly, before considering hypotheses about how students control their learning, we briefly discuss a framework of object-level processing, the cognitive load theory (CLT), which is a framework commonly used in the literature on learning principle-based concepts (e.g., Paas, Renkl, & Sweller 2003; Paas, Van Gog, & Sweller, 2010; Sweller, 1988, 1994). CLT assumes students have limited cognitive resources that are differentially expended on processing that either promotes or hinders learning (referred to as germane load versus extraneous load, respectively) depending on various factors such as prior knowledge or task complexity. For novices, learning principles ideally involves a transition from schema acquisition to schema application. Worked examples are beneficial during the initial stage of schema acquisition because learners can focus their limited cognitive resources on understanding the principle. If students attempt to apply the principle before a schema is fully developed, they often adopt suboptimal problem solving methods (e.g., a means-end analysis strategy) and schema acquisition suffers. However, once a schema has been sufficiently developed, worked examples become redundant with information already learned and limited resources can be better spent on practicing schema application via problem-solving to increase learning outcomes (Kalyuga, 2007; Kissane, Kalyuga, Chandler, & Sweller, 2008; Renkl, Atkinson, & Große, 2004; Renkl, Atkinson, Maier, & Staley, 2002).

Consistent with these theoretical assumptions, when novices begin by studying worked examples prior to problem solving (*W*orked *E*xamples followed by *P*roblem *S*olving, or a *WEPS* schedule), they have greater benefits in learning compared to when they only solve problems (e.g., Carroll, 1994; Cooper & Sweller, 1987; Kalyuga & Sweller, 2004; Mwangi & Sweller, 1998; Retnowati, Ayres, & Sweller, 2010; Rourke & Sweller, 2009; Sweller & Cooper, 1985; Sweller, 1988; Sweller, Chandler, Tierney, & Cooper, 1990; Ward & Sweller, 1990). The benefit of WEPS schedules (in which one studies a worked example of a problem and then solves a new one) is greater than solving a problem first and then reviewing a worked example (Leppink, Paas, Van Gog, Van der Vleuten, & Van Merriënboer, 2014; Van Gog, Kester, & Paas, 2011). Furthermore, WEPS schedules that involve a technique known as *fading*—which involves transitioning from fully worked examples to presenting part of a worked example and having the participant solve the rest—often produce better performance as compared to a standard WEPS schedule (Atkinson, Derry, Renkl, & Wortham, 2000; Renkl et al., 2004; Renkl et al., 2002; but see; Reisslein, Atkinson, Seeling, & Reisslein, 2006). Given that knowledge acquisition is gradual, the intermediate scaffolding provided by faded examples supports the transition from schema acquisition to schema application. In summary, the key aspect of the practice schedule that is normatively most effective for novice learners is the scheduling of worked examples prior to problem solving.

In the present studies that investigate problem solving by novices, what kind of study schedule will students use? Possible answers to this question cannot be derived from theory of object-level processing (e.g., cognitive load theory) because the monitoring-control relationship that involves the meta-level is relevant. According to the *monitoring-affects-control* hypothesis (Nelson & Leonesio, 1988), learners monitor their progress and control subsequent learning by focusing more study on items judged as least-well learned (vs. more-well learned). This hypothesis has been confirmed many times in contexts where students are attempting to memorize simple stimuli (for reviews, see citations; Metcalfe & Kornell, 2005; Dunlosky & Ariel, 2011). Moreover, students view self testing—which is akin to simulating the criterion test—as a means to *monitor* their progress (e.g., Hartwig & Dunlosky, 2012; Kornell & Bjork, 2007). For instance, when given unlimited time to master a list of words for an upcoming criterion test, students will try to recall the words from memory (i.e., without looking at the list), so as to decide whether they are ready to take the criterion test or need to study more (e.g., Murphy, Schmitt, Caruso, & Sanders, 1987).

In the present context where students are learning to solve problems, they have the option to either solve a problem or study a worked example. In the context of the SRL framework, solving a problem represents a means to monitor using a self test, which can then inform a decision about whether studying a worked example is needed. This distinction leads to the following two expectations. First, students will typically begin studying by solving a problem, so as to monitor how well they can already solve it. The expectation here is that many students will not begin with a worked example, which is normatively most effective (as expected from cognitive load theory). Second, the monitoring-affects-control hypothesis predicts what students will do after attempting to solve a problem. If they incorrectly solve a particular kind of probability problem (e.g., one where the order of events is relevant), they will be more likely to study a worked example than to solve another problem of the same kind. By contrast, if they correctly solve a problem, they will be more likely to stop studying that particular kind of problem than to study a worked example or attempt to solve another problem of that kind.

1.2. Overview of current experiments

Given the lack of research relevant to students' use of problem solving and worked examples while regulating their learning, the purpose of the current study was to examine how learners control their example-based learning of principles. To this end, we conducted three experiments in which novices learned how to solve two types of probability problems. In Experiment 1, after an initial pre-knowledge