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The Effect of Worked Examples and Retrieval Practice on Primary School Students' Mathematical Problem-Solving Performance

Sterre K. Ruitenburg[1], Gino Camp[1], Paul A. Kirschner[1,2], and Halszka M. Jarodzka[1]

[1] Department of Online Learning and Instruction, Faculty of Educational Sciences, Open University of the Netherlands, the Netherlands

[2] Expertise Centre Effective Learning (ExCEL), Thomas More University of Applied Sciences, Belgium

Abstract

Practice strategies are ways to practice with new subject matter after initial instruction or self-study. To help students acquire (mathematical) problem-solving skills, two practice strategies are generally effective: practicing through worked examples and practicing through retrieval practice. However, it is not yet fully understood *when* each practice strategy should be used, despite the practical value of this knowledge for (mathematics) textbook authors, teachers, and students. To better understand what strategy works under which conditions, we propose to integrate two existing perspectives that were recently put forward into one new model. In this model, we argue that the optimal practice strategy depends on both the complexity of the learning task and on the time between the last practice opportunity and the test (i.e., the retention interval). We propose a preregistered multi-classroom experiment to test this model. More specifically, we plan to use a 2 (Task Complexity: simple vs. complex) x 2 (Practice Strategy: worked examples vs. retrieval practice) x 2 (Retention Interval: 5 minutes vs. 1 week) between-subjects design, with 22 participants per cell (N = 176). We also plan to perform a Bayesian 2 x 2 x 2 ANCOVA on participants' problem-solving performance to test the three-way interaction effect of task complexity, practice strategy, and retention interval (Hypothesis 1), the two-way interaction effect of task complexity and practice strategy after 5 minutes (Hypothesis 2), and the two-way interaction effect of task complexity and practice strategy after 1 week (Hypothesis 3). During our Round Table presentation, we will discuss (a) any questions we have about received reviewers' comments, (b) the viability and value of the theoretical integration we propose, and/or (c) our first ideas on analysing the moderating qualities of (initial retrieval) effort and initial retrieval success.

Keywords: worked examples, retrieval practice, (mathematical) problem-solving, task complexity, retention interval

Introduction

To help students acquire (mathematical) problem-solving skills, two practice strategies are generally effective. When practicing through *worked examples*, students study the problem formulation and the final solution, typically accompanied with the solution steps leading from the former to the latter (for review, see Renkl, 2014). When practicing through *retrieval practice*, students retrieve information from long-term memory while solving a problem rather than restudy that information (for review, see Adesope et al., 2017). To help improve mathematics performance (practical relevance) and to better understand what strategy works under which conditions (scientific relevance), we aim to integrate Chen et al.'s (2018) and Yeo and Fazio's (2019) perspectives on when worked examples and retrieval practice foster students' problem-solving performance (objective) into one model.

In this model, we argue that the optimal practice strategy depends on both the complexity of the learning task and the time between the last practice opportunity and the test (i.e., the retention interval). According to our model, learners first need worked examples to induce the logic underlying the problem-solving procedure. Then, they need retrieval practice to remember this procedure in the long-term (i.e., for fluency building). The greater the *task complexity*, the more logic induction is required and, hence, the more worked examples learners need to adequately induce the logic underlying the problem-solving procedure. The longer the *retention interval*, the more fluency building is required and, hence, the more learners need retrieval practice to adequately remember this procedure in the long-term.

Based on Chen et al.'s (2016) and Hanham et al.'s (2017) findings, we expect a three-way interaction effect of task complexity, practice strategy, and retention interval (Hypothesis 1). After a retention interval of *5 minutes*, we expect a worked example effect for complex tasks (as in both Chen et al. and Hanham et al.) but no or a smaller worked example effect for simple tasks (Hypothesis 2). After a retention interval of *1 week*, we expect a testing effect for simple tasks (as in both Chen et al. and Hanham et al.) but no or a smaller testing effect for complex tasks (Hypothesis 3).

Method

Participants

To achieve a power of .90 for all proposed hypothesis tests, 176 typically-developing Dutch 10-to-11-year-old students participate.

Design

We use a 2 (Task Complexity: simple vs. complex) x 2 (Practice Strategy: worked examples vs. retrieval practice) x 2 (Retention Interval: 5 minutes vs. 1 week) between-subjects design.

Apparatus, Materials, and Instruments

Apparatus

Participants complete the experiment, which is programmed in LimeSurvey (Version 3.17.0; https://www.limesurvey.org), on individual laptops.

Materials

Two sets of *study* materials in the form of instructional videos are used: one for the Simple-condition and one for the Complex-condition. Participants in the Simple-condition are taught how to solve a simple mathematical equation requiring *two* solution steps (e.g., 2 x □ + 4 = 10). Participants in the Complex-condition are taught how to solve a complex mathematical equation requiring *four* solution steps (e.g., 2 x (□ + 2) = 2 + 8).

Four sets of *practice* materials are used: one for the Simple + Worked examples-condition, one for the Simple + Retrieval practice-condition, one for the Complex + Worked examples-condition, and one for the Complex + Retrieval practice-condition. All four sets of practice materials comprise three subsets of five new practice problems. All practice problems are analogous to the problem covered in the study materials.

Two sets of *test* materials are used: one for the Simple-condition and one for the Complex-condition. Both sets comprise 10 new test problems. All test problems are analogous to the study and practice problems.

Instruments

Participants self-report their *age* and *sex*. Participants' *prior mathematical knowledge* is measured using the most recent teacher-administered standardised test in mathematics. Participants' *problem-solving performance* (i.e., the percentage of required solution steps performed correctly) is measured using the test materials. Test reliability and interrater reliability are assessed post hoc.

Procedure

The three-phase experiment takes place in the classroom. First, in a 10-minute *study* phase, participants receive instruction by watching the instructional video for their condition once and without pausing. Second, in a 20-minute *practice* phase, participants practice the problem-solving procedure by working through the practice materials for their condition in a self-paced manner. Third, in a 10-minute *test* phase (after either a 5-minute- or a 1-week delay), participants complete the test for their condition in a self-paced manner.

Data Analysis

To test our model statistically, we perform a Bayesian 2 x 2 x 2 ANCOVA with task complexity, practice strategy, and retention interval as factors and participants' problem-solving performance as dependent variable. We include participants' prior mathematical knowledge as a covariate. Also, to take the nested data structure into account, we include teacher ID and school ID as predictors. We test the three-way interaction effect of task complexity, practice strategy, and retention interval (Hypothesis 1) and the two-way interaction effects of task complexity and practice strategy after retention intervals of 5 minutes (Hypothesis 2) and 1 week (Hypothesis 3). Data will be collected in March 2022 and will be presented at the SIG meeting.

Round Table presentation

During our Round Table presentation, we will briefly introduce our study (5 minutes) followed by a group discussion (25 minutes) on (a) any questions we have about received reviewers' comments, (b) the viability and value of the theoretical integration we propose, and/or (c) our first ideas on analysing the moderating qualities of (initial retrieval) effort and initial retrieval success.

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