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The benefits of computer-generated feedback for mathematics problem solving

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A R T I C L E   I N F O

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A B S T R A C T

The goal of the current research was to better understand when and why feedback has positive effects on learning and to identify features of feedback that may improve its efficacy. In a randomized experiment, second-grade children received instruction on a correct problem-solving strategy and then solved a set of relevant problems. Children were assigned to receive no feedback, immediate feedback, or summative feedback from the computer. On a posttest the following day, feedback resulted in higher scores relative to no feedback for children who started with low prior knowledge. Immediate feedback was particularly effective, facilitating mastery of the material for children with both low and high prior knowledge. Results suggest that minimal computer-generated feedback can be a powerful form of guidance during problem solving.

Introduction

Feedback often has powerful positive effects for children across development. For example, feedback has been shown to improve performance for preschoolers on a card sort task (Bohlmann & Fenson, 2005), middle school students on a writing assignment (Gielen, Peeters, Dochy, Onghena, & Struyven, 2010), and undergraduates on a multiple-choice test of general knowledge (Butler & Roediger, 2008). However, the effects of feedback are not universally beneficial (Mory, 2004). The goal of the current research was to better understand when feedback has positive effects and to identify

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features of feedback that may improve its efficacy. Specifically, we manipulated the presence and timing of feedback to experimentally test their impact on children's mathematics learning.

The mixed effects of feedback

In most learning contexts, the purpose of feedback is to provide information that the learner can use to confirm or modify prior knowledge. This feedback can promote the correction of errors (Kulhavy, 1977) and increase motivation (Mory, 2004). In many cases, feedback is helpful as intended and improves learning and performance. Indeed, meta-analyses consistently show that, on average, feedback has a positive effect relative to no feedback (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Kluger & DeNisi, 1996). However, the impact of feedback varies, and under some circumstances feedback can have neutral or negative effects (see Hattie & Gan, 2011). For example, negative effects have occurred for both right/wrong feedback (Pashler, Cepeda, Wixted, & Rohrer, 2005) and correct-answer feedback (Hays, Kornell, & Bjork, 2010) on adults' word learning.

Recent research suggests that learners who already have some knowledge in the domain are especially likely to experience negative effects of feedback. For example, in Fyfe, Rittle-Johnson, and DeCaro (2012), second- and third-grade children solved novel math problems. Some children received trial-by-trial right/wrong feedback, whereas others received no feedback. For children with low prior knowledge on the pretest, feedback resulted in *higher* posttest scores than no feedback. However, for children with higher prior knowledge, feedback resulted in *lower* posttest scores than no feedback. Similar results were found when prior knowledge was manipulated via instruction on a correct strategy (Fyfe & Rittle-Johnson, 2016). Given that feedback *can* hinder learning under certain circumstances, more research is needed to understand when and why this occurs and to identify features of feedback that may improve its efficacy.

The timing of feedback

The timing of feedback may be one feature that influences the efficacy of feedback. Some researchers believe that feedback should be given immediately after a response in order to eliminate incorrect ways of thinking and reinforce correct ones (Skinner, 1954). Furthermore, immediate feedback may provide motivation to practice because progress can be easily monitored (Shute, 2008). However, others believe that delaying feedback is more beneficial. First, it may prevent learners from becoming over-reliant on the immediate presentation of feedback, which in turn may increase the need to exert effort on one's own response (Bangert-Drowns et al., 1991). Second, delaying feedback allows for the strength of initially incorrect responses to dissipate, which may make processing correct responses easier (Kulhavy, 1977). Finally, delaying feedback allows for spaced presentation of information (Butler, Karpicke, & Roediger, 2007).

Several meta-analyses point to the advantages of immediate feedback, particularly in computer-based instruction (Azevedo & Bernard, 1995) and applied classroom studies (Kulik & Kulik, 1988). Indeed, multiple experiments have demonstrated the superiority of immediate feedback over delayed feedback for the acquisition of verbal materials (Beeson, 1973; Brosvic, Dihoff, Epstein, & Cook, 2006; Dihoff, Brosvic, & Epstein, 2003). However, a substantial body of research has found no difference between immediate and delayed feedback (e.g., Nakata, 2015; Smits, Boon, Sluijsmans, & Van Gog, 2008) or significant advantages of delayed feedback (Bangert-Drowns et al., 1991; Butler & Roediger, 2008; Butler et al., 2007; Clariana, Wagner, & Roher Murphy, 2000; Kulhavy, 1977; Metcalfe, Kornell, & Finn, 2009; Smith & Kimball, 2010). For example, Butler and Roediger (2008) had undergraduate students study general knowledge passages and take a multiple-choice test. Feedback after each response resulted in a lower proportion of correct responses on a 1-week posttest than delayed feedback after all test questions were completed.

Recent work has found advantages of delaying feedback even after controlling for key confounds. For example, Metcalfe and colleagues (2009) found that delayed feedback was more effective than immediate feedback for sixth-grade students' vocabulary learning after controlling for the shorter retention interval between delayed feedback and the time of testing (but see Nakata, 2015). Mullet, Butler, Verdin, von Borries, and Marsh (2014) found benefits of delayed feedback after controlling