AERA Submission to Division C (Learning and Instruction), Section 1c (Mathematics)

The Role of Feedback Type and Working Memory Capacity During Problem Solving

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Abstract

The effects of feedback during learning are powerful, though variable. We examined two potential moderators of feedback effects during mathematics problem solving: the type of feedback provided and individual differences in working memory capacity. Second- and third-grade children solved unfamiliar math equivalence problems prior to receiving instruction. Children received feedback on their answers (outcome-feedback) or on their strategies (strategy-feedback). Working memory capacity moderated the effect of feedback on children's procedural transfer. Children with lower working memory capacity benefited less from strategy-feedback than outcome-feedback, whereas children with higher working memory capacity benefitted similarly from the two types of feedback. Results suggest that mathematics problem solving can be optimized by considering both characteristics of the learner and the learning environment.

Keywords: Mathematics Education, Cognitive Processes/Development, Learning Processes/Strategies

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Objectives

In the current study, we examined the role of working memory in learning from problem-solving feedback. Specifically, we examined the cognitive demands of two different feedback types and how individual differences in working memory capacity impact their effects. Although both feedback type and individual learner differences are thought to play important roles in the utility of feedback, empirical evaluations are lacking. We examined the impact of feedback in the context of children learning to solve math equivalence problems (e.g., $3 + 4 + 5 = 3 + \_\_$), which require an understanding that both sides of an equation represent the same quantity. Elementary school textbooks do not typically include math equivalence problems and many elementary school children solve them incorrectly (e.g., McNeil & Alibali, 2005).

Theoretical Framework

The role of feedback during learning and problem solving has been studied extensively (cf. Hattie & Gan, 2011). In learning contexts, the purpose is to provide information that the learner can use to confirm, reject, or modify prior knowledge. However, the effects of feedback in general are quite variable (e.g., Mory, 2004). Recent reviews have called for work to specify key moderators to better understand feedback effects (Hattie & Gan, 2011).

The type of feedback provided (e.g., focused on outcomes, strategies, effort, speed) is a key characteristic of feedback to consider. It guides learners' attention and narrows the type of information the learner processes and potentially corrects (Kluger & DeNisi, 1996). Here, we focus on two types of feedback: *outcome-feedback,* information about the accuracy of the learner's response, and *strategy-feedback,* information about how the learner obtained that response. Outcome-feedback is one of the most common types of feedback and it generally benefits learning compared to no-feedback controls (Kluger & DeNisi, 1996). Research suggests that it functions primarily by helping learners correct inaccurate information (e.g., Anderson et al., 1972). Yet, many researchers recommend focusing feedback more specifically on learners' strategies (e.g., Early et al., 1990; Luwel et al., 2011; Smith & Ragan, 1993). Strategy-feedback concerns the processes that generate outcomes, as opposed to the outcomes themselves. Research suggests that strategy feedback often improves strategy selection (e.g., Luwel et al., 2011) and promotes greater transfer than outcome-feedback (e.g., Schunk & Swartz, 1993).

Though strategy-feedback has potential advantages relative to outcome-feedback, it may not be effective for all learners. For example, different feedback types may require different levels of cognitive resources to process (e.g., Mory, 2004). Several models of feedback are specifically concerned with internal cognitive processes that affect how feedback is perceived and used (Clariana et al., 2000; Kulhavy & Stock, 1989). For example, Kulhavy and Stock (1989) suggest that processing feedback includes relating it to the initial response, integrating it with prior knowledge, and evaluating one's performance. All of this processing takes place in *working memory* (WM), a short-term system that enables individuals to actively control, maintain, and regulate a limited amount of task-relevant information (Miyake & Shah, 1999). WM capacity varies across individuals (Alloway, 2006); thus, individual differences in working memory capacity may impact learning from different feedback types.

In general, strategy-feedback may tax WM resources to a greater extent than outcome-feedback. First, strategy-feedback is less common than outcome-feedback and hence less familiar to most learners. As familiarity with a task or technique increases, WM resources are used to a lesser extent (Anderson, 1982). Second, because math problems generally involve multi-step strategies to single solutions, processing strategy-feedback may require more resources and more time than processing outcome-feedback.

For children with lower WM capacity, the demands may overwhelm limited resources and impede learning from strategy-feedback (e.g., Sweller et al., 1998). Thus, lower-capacity children may instead benefit more from outcome-feedback. The simple, direct feedback may focus their attention on key information without requiring excessive feedback-related processing. However, for learners with higher WM capacity, strategy-feedback may represent a "desirable difficulty" (Bjork, 1994). That is, strategy-feedback may place greater demands on WM relative to outcome-feedback, but not enough to overwhelm their resources.

Method

*Participants***.** Participants were 64 second- and third-grade children (35 female) attending one of two elementary schools in the U.S. The participants were predominantly ethnic minorities (98% African American; 2% White) and the mean age was 7.9 years (min = 6.8, max = 9.8). All of these children scored below 80% on the pretest.

Design and Procedure. We used a pretest-intervention-posttest design with a two-week retention test. Children completed a written pretest in their classrooms in one 20 minute session. Next, they completed a one-on-one tutoring intervention and posttest lasting 50 minutes. Two weeks later they took the retention test in their classrooms. Children were randomly assigned to one of two intervention conditions: outcome-feedback (n = 33) or strategy-feedback (n = 31).

During the intervention, children solved 12 math equivalence problems (e.g., 5 + 3 + 9 = 5 + __) and received feedback after each one. In the outcome-feedback condition, children reported their numerical answer and the experimenter stated whether it was a correct or an incorrect answer (e.g., Good try, but you did not get the right answer.). In the strategy-feedback condition, children reported how they solved each problem and the experimenter stated whether it was a correct or an incorrect strategy (e.g., Good try, but that is not a correct way to solve the problem.). Immediately following problem solving, children rated their subjective cognitive load. This was followed by a conceptual instruction phase during which all children received brief instruction on the meaning of the equal sign. At the end of the intervention, we administered the posttest and then measured children's working memory capacity.

Data Sources

Math Equivalence Assessment. The assessment, adapted from past work, was administered at pretest, posttest, and retention test (Rittle-Johnson et al., 2011). It included procedural learning and procedural transfer items (see Table 1), which required children to solve math equivalence problems. The learning items were similar to those presented during the intervention and the transfer items differed from those presented during the intervention (e.g., inclusion of subtraction). To establish reliability on children's problem-solving strategies, a second rater coded 30% of the responses. Agreement was high (kappa = .97).

Subjective Cognitive Load. Three items measured children's cognitive load. The first item was a subjective rating of task difficulty (Paas, 1992): "How easy or hard was it to solve all of those problems?" Children responded on a 7-point scale. The two remaining items were modified from the NASA Task Load Index (Hart & Staveland, 1988). These items measured mental effort ("I had to work hard to solve those problems.") and frustration ("I was stressed and irritated when I solved those problems."). Children indicated their agreement on a 5-point scale.

Working Memory Capacity. WM capacity was measured using the backward digit span task (Wechsler, 2003). Children were read a series of numbers and asked to repeat the numbers in reverse order. Series length began at 2 and ended at a maximum of 8. These were two items per series length. The task was discontinued when children recalled both items in a series incorrectly. WM scores consisted of the number of series that the child correctly recalled.

Results

Pretest. Children had low to moderate knowledge of math equivalence at pretest. Importantly, children's performance on the procedural items at pretest ($M = 28\%$, $SD = 20\%$) did not differ as a function of condition, $F < 1.1$, or WM capacity, $r = .04$.

Posttest and Retention Test. We examined children's procedural learning and procedural transfer as a function of condition, WM capacity, and their interaction using two repeated-measures ANCOVAs with condition as a between-subject variable and time (posttest and retention test) as a within-subject variable. Pretest scores and age were included as covariates.

There were no effects for the procedural learning items ($M = 42\%$, $SE = 5\%$). Thus, children solved problems like those presented during the intervention moderately well.

For procedural transfer, there were no effects of time, condition, or WM, Fs < 2.2. However, there was a significant condition by WM interaction, $F(1, 57) = 5.46$, $p = .02$, $\eta_p^2 = .09$ (see Figure 1). To explore this interaction, we examined the impact of condition for children at one standard deviation below (lower WM) and above (higher WM) the mean. For children with lower WM capacity, strategy-feedback resulted in significantly lower transfer performance ($M = 27\%$) than outcome-feedback ($M = 57\%$), $F(1, 57) = 4.84$, $p = .03$, $\eta_p^2 = .08$. In contrast, for children with higher WM capacity, strategy-feedback ($M = 45\%$) resulted in relatively higher transfer performance than outcome-feedback ($M = 30\%$), although this effect did not reach significance, $F(1, 57) = 1.24$, $p = .27$, $\eta_p^2 = .02$. Overall, WM moderated the impact of condition on procedural transfer, and this effect was robust across time.

Cognitive Load. We analyzed the three measures of cognitive load separately as each taps a different aspect of cognitive load. Children in the strategy-feedback condition reported higher levels of effort, $p = .04$, and frustration, $p = .03$, than children in the outcome-feedback condition. Ratings of task difficulty did not differ by condition, $p = .25$. There were no main effects of WM, nor did condition interact with WM for any measure, Fs < 1.2. Overall, these results suggest that strategy-feedback resulted in higher perceived effort and frustration than outcome-feedback, regardless of WM capacity.

Scholarly Significance

In contrast to researchers' suggestions (e.g., Earley et al., 1990; Luwel et al., 2011), we found no evidence that feedback on solution strategies can be more beneficial than feedback on solutions, and some evidence that it can be detrimental. For children with higher WM capacity, the differences between feedback conditions were not reliable, though strategy-feedback resulted in somewhat higher transfer. For children with lower WM capacity, feedback on strategies was less effective than feedback on solution outcomes for transfer. This current study is one of few to experimentally examine the use of strategy-feedback in mathematics (e.g., Luwel et al., 2011). The findings suggest that educators should carefully consider the content of feedback provided.

The cognitive load results reveal one potential reason for the moderating effects of WM capacity. Children who received strategy-feedback reported higher levels of mental effort and frustration than children who received outcome-feedback. Although these ratings did not differ as a function of WM capacity, the increased perceptions of load may have been more detrimental for children with lower WM capacity. Specifically, the cognitive demands of strategy-feedback may have overwhelmed their limited WM resources and thus hindered their ability to process the problems in a deep manner. Processing the extensive feedback itself (e.g., the content, how to use it) may have directed attention and effort away from aspects of the problem key for transfer (e.g., Sweller et al., 1998). In contrast, the direct, familiar outcome-feedback may have been processed more easily, freeing up more resources to focus on the problems. Children with higher WM capacity, however, were less impacted by feedback type. High-capacity children may have had sufficient resources to process either feedback type without experiencing cognitive overload. These findings support a growing number of studies focused on the potential detrimental effect of cognitive overload in learning settings (e.g., Kalyuga, 2007).

These results also contribute to a body of literature indicating that WM capacity is an important cognitive construct that should be considered in learning contexts (e.g., Sweller et al., 1998). WM is thought to play an important role in a wide range of tasks relevant to learning, including reasoning and problem solving (cf. Conway et al., 2005). In support of this view, the present study suggests the need to consider learners' WM capacity in relation to the instructional method employed and the cognitive load inherent in learning contexts. This is consistent with calls to be mindful of lower WM capacity in formal learning contexts and to simplify instructional practices when possible (e.g., Alloway, 2006).

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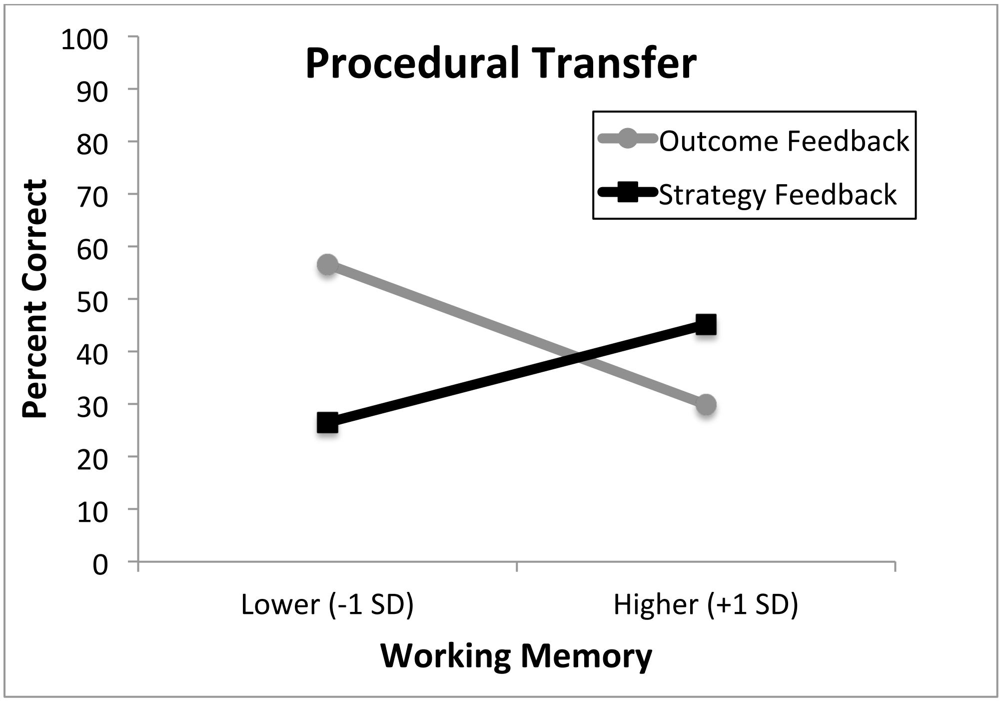
Table 1

Items from the Math Equivalence Assessment

Procedural Learning Items (α = .69)	**Procedural Transfer Items (α = .76)**
8 = 6 + __	__ + 2 = 6 + 4
3 + 4 = __ + 5	8 + __ = 8 + 6 + 4
3 + 7 + 6 = __ + 6	5 + 6 – 3 = 5 + __
7 + 6 + 4 = 7 + __	5 – 2 + 4 = __ + 4

Figure 1

Procedural Transfer Scores by Feedback Condition and Working Memory Capacity



Note. Scores are estimated based on posttest and retention test scores. Nonstandardized coefficients are plotted at ± 1 standard deviation from the mean.