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Is strategy variability advantageous? It depends on grade and type of strategy☆

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ABSTRACT

No research to date has examined whether variability in mathematics strategy use is linked to higher performance or whether there are long-term benefits to students who use a broad variety of strategies. The goal of the present study was to examine the relationship between strategy variability and student competency in mathematics. Longitudinal data were collected from 241 second and fourth graders on their variability in strategy use, fluency, and end-of-year mathematics competency scores. Results indicated that strategy variability dropped significantly as students progressed from the second to the fourth grade. Strategy variability positively predicted mathematics achievement in the second grade but negatively predicted achievement in the fourth grade. Students who were more fluent in the second grade showed less strategy diversity in the fourth grade. Higher strategy variability in the second grade was correlated with higher fluency in the fourth grade. The study indicates that early variability in strategy use is linked to positive outcomes in later years.

1. Introduction

Despite the importance of elementary school mathematics on later participation and success in mathematics and science, elementary school students in the United States have significant deficiencies in mathematics (e.g., NCES, 2011). A number of factors affect mathematics achievement in elementary school, two of which are computational fluency and computational strategy use (Bull, Espy, & Wiebe, 2008; Geary, Hoard, Byrd-Craven, & DeSoto, 2004). Computational fluency, or speed of problem solving, is thought to be a function of a tightly organized representation of number and is believed to support children's acquisition of complex mathematical concepts by freeing working memory (Ashcraft, Donley, Halas, & Vakali, 1992; Geary, 1994). Computational strategy use, particularly more advanced strategies, is believed to emerge out of a rich conceptual knowledge about number (Steffe, 1983). It is assumed that children acquire an array of computational strategies (Siegler & Jenkins, 1989), and that the use of a variety of computational strategies supports mathematics achievement (Baroody, 2003; Heinze, Star, & Verschaffel, 2009). Programs promoting children's construction of mathematics computation strategies have been developed and tested (e.g., Carpenter, Franke, Jacobs, Fennema, & Empson, 1998; Carr, Taasoobshirazi, Stroud, & Royer, 2011), but we have yet to determine whether strategy variability actually provides an advantage to students (Verschaffel, Torbeyns, De Smedt, Luwel, & Van Dooren, 2007b).

While there is strong evidence for the importance of computational fluency for mathematics achievement (e.g., Carr & Alexeev, 2011), the research is less clear about the importance of strategy variability, particularly the use of multiple strategies at any given time. Instructional studies show that having students compare different strategies improves learning and strategy variability (Rittle-Johnson & Star, 2007; Star & Rittle-Johnson, 2008), but other work indicates that strategy variability is not predictive of mathematics learning (Alibali, 1999). No research has explicitly examined whether variability in mathematics computational strategy use is linked to higher performance or whether there are long-term benefits to students who use a broad variety of strategies.

Variability in computational strategy use in mathematics has primarily been defined in two ways: the number of strategies observed during problem solving (e.g., Siegler, 1996) and the number of shifts in those strategies over time (e.g., Siegler & Jenkins, 1989). For the purposes of this study, we defined strategy variability as the number of computational strategies a given child uses at least once when solving mathematics problems. Fluency in this study is defined as the speed with which children correctly answered single digit arithmetic problems so that high scores indicate slower performance and lack of fluency. Although others (Royer, Tronsky, Chan, Jackson, & Marchant, 1999) have defined fluency as the speed for correct and incorrect strategy use, fluency as defined in this study controlled for impulsive responses.

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1.1. Strategy variability

It is argued that variability in strategy use within individuals is the norm and we must understand this variability in order to understand cognitive development (Heirdsfield & Cooper, 2002; Siegler, 2007). Siegler (1996) proposes that the relationship between task experience and strategy variability is an inverted U shape. Children with almost no experience with a particular task have few, if any, strategies for solving the task. As they gain experience with the task, they acquire multiple strategies of varying effectiveness. Over time, less effective strategies are winnowed out and a few effective strategies remain. In regard to arithmetic, young children use many different computational strategies as they learn to solve addition and subtraction problems, including counting on fingers and retrieval (e.g., Siegler & Shrager, 1984), but over time they reduce the number of strategies they use (Biddlecomb & Carr, 2011; Siegler & Jenkins, 1989) as they discard computational strategies, such as finger counting, in favor of more fluent strategies, such as retrieval (Lemaire & Siegler, 1995). Not all children, however, shift to more advanced computational strategies; some poorer performing children retain a pattern of strategy use that reflects a concrete representation of number (Biddlecomb & Carr, 2011). Overall, strategy variability is argued to be more useful when children are first learning a task, when a learner can explore strategies to determine what works and to settle on the best and most effective strategies (Coyle & Bjorklund, 1997; Coyle, Read, Gaultney, & Bjorklund, 1998; Hansberger, Schunn, & Holt, 2006).

The research on strategy variability in other domains also suggests that variability is most useful when strategies are first being learned and used. Coyle and Bjorklund (1997) found a negative relationship between strategy variability and recall on a memory task for fourth grade children and a non-significant, but positive relationship for second and third grade children. Hansberger et al. (2006) found that high strategy variability (as measured by changes in coaching, metacognitive, and associative strategies) was linked to better performance coaching a simulated football team initially, but with experience less strategy variability was related to better performance.

There are several reasons to view strategy variability as being good for achievement, especially early on. Some researchers (e.g., Goldin-Meadow, Alibali, & Church, 1993) view cognitive variability as evidence of cognitive conflict among conflicting strategies or rules for solving a problem. This conflict typically occurs as students shift from an incorrect, less advanced strategy to one that is correct and more advanced. Cognitive conflict has its benefits; children who show cognitive conflict through the use of conflicting rules or strategies are more likely to move to more advanced strategies and to transfer those strategies to new tasks. For instance, Alibali and Goldin-Meadow (1993) showed that when children's gestures and verbal reports were inconsistent, they were more likely to apply newly learned knowledge about equivalence when solving addition and multiplication problems.

Having a variety of strategies allows for flexibility in responding to novel problems. Some strategies are more effective on certain problems and less effective on others and it is recommended that children be taught to use a variety of strategies to accommodate different problems (Siegler, 1996; Thompson, 1999). Strategy variability is also thought to give children an advantage as they encounter new and different problem types for which the typical strategies are less effective (Alibali, 1999).

There is an opposing argument, however, that having a broad repertoire of strategies may be problematic for less advanced mathematics students. The argument is that students who are more mathematically advanced will be able to make good choices in matching strategies to problems. This flexibility, however, should not be an objective for younger students or students who struggle in mathematics because these students tend to have lower working memory which could cause problems with cognitive load during problem solving (Threlfall, 2002; Verschaffel, Greer, & De Corte, 2007a). There is some supporting research that indicates that children with low mathematics achievement have difficulty shifting their strategy use (Bull, Johnston, & Roy, 1999; Bull & Scerif, 2001). From this perspective, strategy variability among young or struggling students can be counterproductive.

Strategy variability is also a function of the classroom and may not necessarily translate into improved learning and higher achievement (Alibali & Goldin-Meadow, 1993). Most children develop mathematics strategies within the context of the classroom where strategies are often explicitly instructed (Perry & Elder, 1997). When strategies are taught by the teacher, the use of these strategies may not reflect a conceptual understanding of number and may not result in improved achievement. In addition, Ellis (1997) argues that children develop an implicit understanding about what a given culture or context defines as appropriate, useful, and wise. Students have been found to prefer fast and accurate strategies, such as mental counting and retrieval, over slower strategies that involve the use of concrete manipulatives because these strategies are viewed as evidence of higher ability (Carr, Jessup, & Fuller, 1999).

As applied to complex arithmetic, strategy variability could be evidence of conflicting mental models of number, presumably with the use of both manipulative-based and cognitive strategies being evidence of a transition to a more advanced conceptual structure. Alternatively, strategy variability could be the result of classroom experiences that press students to shift to more advanced strategies or to simply use an array of strategies. If the case is that the variability of strategies reflects new conceptual understanding, then it would be expected to be linked to better achievement. However, if it is a result of social influences and if variability produces cognitive overload, that may not be the case.

When the goal is to move to a more advanced conceptualization of mathematics, it makes no sense to maintain the use of less efficient computational strategies. In line with this, a number of studies have indicated that more advanced, cognitive strategy use has been linked to better performance, whereas the use of manipulative-based strategies (e.g., finger counting) during complex computation tends to be negatively linked to mathematics competency (Carr, Steiner, Kyser, & Biddlecomb, 2008; Geary, Bow-Thomas, & Yao, 1992; Widaman, Little, & Geary, 1992). Therefore, using a variety of strategies that involve manipulatives and cognitive strategies may be helpful in the second grade, when students are first exploring different strategies, but not in the fourth grade when students should be more streamlined in their strategy use.

1.2. Fluency and strategy variability

It is argued that fluency on basic math facts supports the emergence of more complex strategies and is linked to later achievement. Work on complex arithmetic shows that the transition from strategies that involve concrete representations to strategies that involve the mental representation of number is supported by earlier computational fluency (Carr & Alexeev, 2011). The combination of high fluency and cognitive strategy use significantly predicts later achievement (Carr & Janes, 2007). When children are fluent in the computation and retrieval of basic facts from long-term memory, this allows for more room in working memory and permits cognitive resources for faster processing and more complex problem solving (e.g., Adams & Hitch, 1998). As such, fluency on basic math facts would be expected to predict students dropping less efficient strategies in favor of efficient, cognitive strategies. What is unknown is whether fluency on basic math facts predicts the emergence of strategy variability, as would be the case if a rich, network of basic math facts is linked to higher variability. Conversely, fluency could be negatively related to variability as would be the case if children's fluency leads to the adoption of fewer, more advanced strategies.

A second question focuses on whether strategy variability predicts later fluency on basic math facts. On the one hand, if strategy variability is evidence of confusion and a failure to develop a set of efficient