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Children's understanding of additive concepts

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Most research on children's arithmetic concepts is based on one concept at a time, limiting the conclusions that can be made about how children's conceptual knowledge of arithmetic develops. This study examined six arithmetic concepts (identity, negation, commutativity, equivalence, inversion, and addition and subtraction associativity) in Grades 3, 4, and 5. Identity ($a - 0 = a$) and negation ($a - a = 0$) were well understood, followed by moderate understanding of commutativity ($a + b = b + a$) and inversion ($a + b - b = a$), with weak understanding of equivalence ($a + b + c = a + [b + c]$) and associativity ($a + b - c = [b - c] + a$). Understanding increased across grade only for commutativity and equivalence. Four clusters were found: The Weak Concept cluster understood only identity and negation; the Two-Term Concept cluster also understood commutativity; the Inversion Concept cluster understood identity, negation, and inversion; and the Strong Concept cluster had the strongest understanding of all of the concepts. Grade 3 students tended to be in the Weak and Inversion Concept clusters, Grade 4 students were equally likely to be in any of the clusters, and Grade 5 students were most likely to be in the Two-Term and Strong Concept clusters. The findings of this study highlight that conclusions about the development of arithmetic concepts are highly dependent on which concepts are being assessed and underscore the need for multiple concepts to be investigated at the same time.

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Introduction

Researchers and educators are increasingly recognizing the importance of conceptual knowledge in the development of children's arithmetic skills (Rittle-Johnson & Schneider, 2015; Siegler & Lortie-Forgues, 2015). As van den Heuvel-Panhuizen and Treffers (2009) noted, acquiring strong calculation skills is not only about learning specific problem-solving procedures but also includes understanding the properties of numbers and operations—that is, having good conceptual knowledge. Conceptual knowledge is critical for mathematical development because not only does it support the development of better problem-solving procedures but also these efficacious problem-solving procedures lead to better knowledge of arithmetic facts and better performance on mathematical tasks and are integral to the development of more advanced mathematical skills such as algebra (Bisanz & LeFevre, 1990; Kilpatrick, Swafford, & Findell, 2001; National Mathematics Advisory Panel., 2008; Nunes et al., 2008).

The importance of conceptual knowledge is further reflected in the increase in research in this area (e.g., see Gilmore & Papadatou-Pastou, 2009, for a meta-analysis of one arithmetic concept). However, the tendency in much of the research is to examine one concept at a time. In recent literature reviews by Prather and Alibali (2009) and Crooks and Alibali (2014), each review focused on three commonly investigated arithmetic concepts (or principles). Prather and Alibali (2009) focused on commutativity, relation to operands, and inversion, whereas Crooks and Alibali (2014) focused on equivalence, cardinality, and inversion. It is striking that in each review, there is hardly any overlap in the researchers investigating each of the three concepts and no researcher had investigated more than two of the concepts either within one study or across several studies. This suggests that, in most cases, researchers are investigating arithmetic concepts in isolation. This isolation not only has led to concerns about how to define conceptual knowledge (Crooks & Alibali, 2014) but also yields questions as to what theories can be proposed and what conclusions can be drawn about how children's conceptual knowledge develops if most studies focus on one concept alone.

The practice of studying arithmetic concepts in isolation not only prolongs the debate on how to define conceptual knowledge but actually may run counter to currently accepted definitions of conceptual knowledge. Conceptual knowledge has historically been difficult to both measure (Bisanz & LeFevre, 1990) and define (Crooks & Alibali, 2014). Yet, one common way to define and measure conceptual knowledge is by considering it as understanding the underlying structure of arithmetic, including knowledge of operations and the relations between different operations and between different concepts (Bisanz & LeFevre, 1990; Hiebert & Lefevre, 1986). This understanding then serves as the basis for problem-solving procedures (Bisanz & LeFevre, 1990; Robinson, Dubé, & Beatch, 2016). Thus, conceptual knowledge is about knowing the relationships between arithmetic concepts, but actual measurement of multiple concepts simultaneously is sparse.

A few studies have examined more than one concept. Baroody, Lai, Li, and Baroody (2009) investigated the understanding of three concepts involving the operation of subtraction in 3- to 7-year-old children using concrete objects and/or word problems. They found that by 4 years of age, nearly 75% of children had a good understanding that subtracting zero from a number left the original number unchanged—the concept of identity ($a - 0 = a$)—and that after 5 years of age, nearly all children had a good understanding of identity. By 4 years of age, just over 50% of children had a good understanding that subtracting a number from itself resulted in zero—the concept of negation ($a - a = 0$)—and once again after 5 years of age, nearly all children had a good understanding of negation. However, children had more difficulties in understanding that when a second number is both added and subtracted to a first number, the first number remains unchanged—the concept of inversion ($a + b - b = a$). Nearly all 4-year-olds failed to demonstrate understanding of inversion, just over 50% of 5- and 6-year-olds understood the concept, but all 7-year-olds were successful. Baroody et al. (2009) noted that understanding negation and identity needed to precede the understanding of inversion, thereby providing important information about the order in which concepts develop, at least on problems involving concrete objects and/or word problems. Other work on inversion shows that children demonstrate an earlier understanding when concrete objects are used than when symbolic problems are used (Gilmore & Bryant, 2006; Klein & Bisanz, 2000).

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