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Link between language, concepts and mathematics: Influence of the semantic content in word-problem solving

Symposium Abstract, MCLS 2024
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Word-problem (WP) solving is a core component of the primary and secondary mathematics curriculum (Common Core Standards for Mathematics, 2010). WP solving is critical to high-school success, but is also the best predictor of employment and income in adulthood (Murnane et al., 2001). However, WP are known to be particularly challenging for children and adults, as they involve understanding a mathematical situation through words. WP solving indeed is a complex and difficult task (Daroczy et al., 2015) and many children struggle to solve them (Fuchs et al., 2015; Lewis & Mayer, 1987; Riley et al., 1983). WP solving involves both numerical and linguistic skills (Daroczy et al., 2015). According to the *Language function hypothesis* (Peng et al., 2020), language serves as a thinking function that contributes to math reasoning. Moreover, the *Semantic Congruence model* (Gros et al., 2020) describes the central role of world semantics in the problem encoding, recoding, and solving. A main difficulty thus concerns the misalignment between the semantic content and the solution of the WP. The researches presented in this symposium will discuss the role of language and concepts in WP solving, in examining the influence of the lexical ambiguity and the semantic content on WP solving of adults and children. The symposium will provide theoretical insights on WP solving and generate empirically-validated recommendations for practice. Understanding WP mechanisms will inform educators to better adapt their teaching.

In the first paper, Ana Taboada Barber (University of Maryland) found in a recent work based on the Language function hypothesis (Peng et al., 2020) that language skill directly and indirectly mediated the influence of executive functions (EF) skills in 8–10-year-old students' math WP performance. In this study, language skills were measured as math lexical ambiguity (i.e., knowledge of ambiguous math word [e.g., operation; expression; order; difference round]). Knowledge of common and math definitions of lexically ambiguous words was assessed with an orally administered 5-item measure adapted from Zipke et al.'s homonym task (2009). Lexical ambiguity mediated the influence of EF skills on math WP in English-Spanish bilingual students' (Cartwright et al., 2022). This follow up study aimed to determine how bilingualism and math performance moderate the mediation of ambiguous math word knowledge between EF skills and math problems. Two moderated mediations were used and results showed that, in 8–10-year-olds, bilingual status and math performance, both moderated the mediation of ambiguous word knowledge between EF skills (working memory, inhibition, and cognitive flexibility) in children's performance on math WP solving. Findings show that students who have further developed bilingualism tend to leverage the use of ambiguous words in the service of math reasoning to a higher degree than students who are less bilingual. Implications are that bilinguals' EFs serve their language knowledge of ambiguous words to foster their reading of math WP.

In the second paper, Anne Lafay, Mélodie Bulinski, and Carole Berger (Université Savoie Mont Blanc) based their work on the Semantic Congruence model (Gros et al., 2020) and assessed the development of children's math WP solving in relation to the unknown of the WP and the semantic content. A total of 16 second, 22 third, and 42 fourth graders were asked to solve 12 *Compare* and 3 *Change* WP (distractors). We manipulated three unknowns (difference, compared, and referent) and four semantic relations (taxonomic such as tiger and rabbit, slot-filler which include contextually-related objects such as cat and dog, one-to-one functional such as pen and cap, and one-to-many functional such as vase and tulip). Analysis showed an effect of the WP unknown, in second and third graders, that greatly depended on the semantic relation. In fact, second and third graders were more likely to correctly solve compared unknown WP than difference unknown WP when they solved slot-fillers WP. This effect was not observed with the three other semantic relations. The results thus suggested an effect of the semantic relation and an effect of contextual cues on children's WP-solving development. Manipulating words that represent objects in the same category and in the same context helped children to consider them in the same category and to add them. On the contrary, manipulating words that represent same category objects non-contextually-related (taxonomic relation) or that represent different-category objects (functional relation) did not enhance children's solving of compared unknown WP.

In the third paper, Hippolyte Gros (CY Cergy Paris University), Jean-Pierre Thibaut (Université de Bourgogne), and Emmanuel Sander (University of Geneva) assessed the nuanced role of non-mathematical content in solving WP in exploring the intersection of mental representations, drawing production, and strategy selection. They used dual-strategy isomorphic WP that shared the same mathematical structure but varied in the entities mentioned in their statements. This variation in the problems' semantic content was hypothesized to prompt some problems to induce a specific (cardinal) encoding aligned with a 3-step solving strategy, while others were thought to encourage an alternative (ordinal) encoding congruent with a 1-step strategy instead. Fifth graders and adults were asked to solve the same 12 arithmetic WP and instructed them to draw a diagram for each. The joint analysis of the drawing and solving tasks revealed that the cardinal and ordinal diagram features correlated with the hypothesized semantic properties of the problems and significantly influenced the choice of solving strategy. This correlation persisted across participants of varied experience levels, indicating that strategy use is governed by problem representation, as shaped by the non-mathematical content in the problem statement. Interestingly, the characteristics of participants' drawings—whether highlighting cardinal or ordinal features—were predictive of their chosen solving strategies, underscoring the drawings' relevance in revealing the underlying semantic influences on problem representation. The findings underscore the value of drawing tasks in exploring mental representations and enhancing mathematical development in educational settings.

In the fourth and final paper, Mélanie Barilaro (Concordia University), Jessica Bourgin, and Anne Lafay (both at Université Savoie Mont Blanc) investigated the impact of the semantic relation between the referent and the compared quantity in solving mathematical compare WP using an eye-tracking method. Undergraduate students ($N = 25$) solved inconsistent compare WP.

Those problems involved either functional (net and fishes), collateral (apple and pear), or control (pie and pie) relation between the referent and the compared quantity. The results showed no difference of performance across the three types of relations, while response time was higher for WP involving functional relation. Furthermore, when solving WP containing functional and collateral relations, participants spent more time fixating the referent and the compared quantity and demonstrated a higher number of revisits on those components, compared to WP containing control relation. Finally, they made more saccades when solving WP containing functional relation compared to collateral and control relations. Taken together, these data show that, despite similar performance in solving inconsistent compare WP containing different types of semantic relations, higher cognitive effort is required to process collateral relations, and, to an even greater extent, functional relations. This study provides important evidence of the impact of semantic knowledge on solving WP.