Children's Generalization of Novel Relational Nouns in Comparison Contexts: An Eye Tracking Analysis

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Abstract

Comparison settings (i.e. several stimuli introduced simultaneously) favor novel word learning and generalization. This study investigates the temporal dynamics of 6-year-olds solving strategies in a relational noun (e.g. "x is the dax for y") comparison and generalization task with eye tracking data. We manipulated conceptual distance between the task's items and recorded children's performances and eye tracking data. We analyze and interpret solving strategies following the predictions made by two hypotheses, the Projection-First and Alignment-first. Eye tracking data clearly revealed that children, first, extract the relation from comparisons of items within a pair and search for a match for the extracted relation, which confirms the predictions of the projection-first hypothesis. Further analyses on error and correct trials suggest that errors occurred in the late, choice, phase of a trial.

Key words: comparison; generalization: eye tracking measures; strategies; relational nouns.

Introduction

Relational nouns refer to categories that are defined by relations between objects rather than by the properties of the objects themselves. A relational noun can be used in many different situations involving many different entities. "Neighbor" for example is a relational noun that can refer to an object, a person, or even an abstract entity but in all these cases neighbor is always defined by the relation "something that is close" rather than by any of the objects', persons', entities' properties. The number of situations in which the same relational noun can be used makes relational nouns more difficult to learn than object nouns (Andrews & Halford, 2002). Children learn relational nouns later than object nouns (Gentner et al., 2011) and often generalize them to object matches instead of relational matches (Gentner & Rattermann, 1991; Christie & Gentner, 2010; Richland et al., 2006)

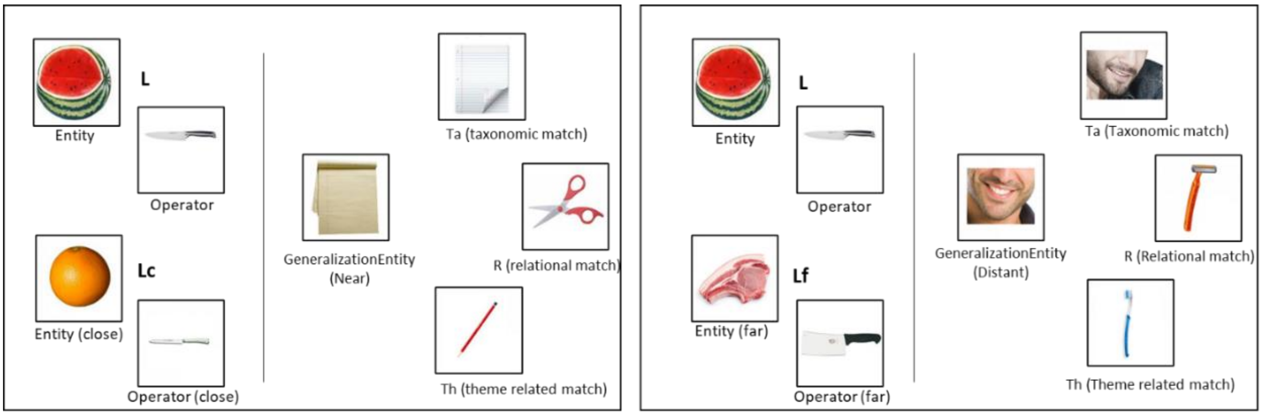
Little is known of the solving strategies that children use to learn and generalize relational nouns. The present study aims to analyze the temporal dynamics of solving strategies that lead to correct relational noun generalization in a comparison setting. We use eye tracking measures to explore children's solving strategies to get a better understanding of how children learn and generalize relational nouns correctly, in an object comparison design (Gentner & Namy, 1999), which to the best of our knowledge has never been done.

Comparison and conceptual distance in relational nouns

A large body of research demonstrates the benefit of comparison situations over non-comparison situations for learning nouns (Graham et al., 2010), adjectives (Waxman & Klibanoff, 2000), and for learning words that refer to transient relations between objects like relational nouns (Gentner et al., 2011; Thibaut & Witt, 2015) and verbs (Childers & Paik, 2009). It has been proposed that comparison favors generalization because an alignment process takes place during comparison that highlights conceptual, non-salient shared properties between compared exemplars, and helps children build a conceptually based representation of the relation before generalization (Gentner & Namy, 1999; Gentner et al., 2011; Graham et al., 2010; Tversky, 1977).

Factors in comparison-generalization tasks have often been studied to try and assess their influence on children's novel word generalization performances. Capitalizing on Gentner et al. (2013) design, Thibaut et al. (2018) tested 3- and 4-years old children in a relational noun comparison and generalization task. Participants compared two pairs of objects illustrating the same targeted relation (e.g. *cutter for*), and then had to generalize the relation. To generalize, children were given an item (i.e. a generalization item, called entity, that could be cut) and had to choose a related item (i.e. a generalization object, called operator, that could cut) from a set of options (i.e., a correct relational match, and two distractors, a taxonomic match and a thematically-related match) See Figure 1 for an example of the design.

The authors manipulated comparison so that children saw either one pair only or could compare two learning pairs. The authors also manipulated conceptual distance between items in the learning pairs and conceptual distance between these items and the generalization items. Results revealed better generalization performances in comparison than in no-comparison settings. In addition, far learning favored near generalization for the older children only. There was no effect of learning distance for the younger children, whatever the generalization distance (near or distant).



A B

Figure 1: Example of a set of stimuli adapted for the relation "*cutter for*" as displayed on a Tobii 120 screen in layout 1 . Item names do not appear in the experiment.
Note: A, crosses close learning and near generalization; B, crosses far learning and distant generalization

This influence of conceptual distance on generalization results can be interpreted in terms of executive functions. We argue that comparisons generate cognitive costs (Augier & Thibaut, 2013). As the conceptual distance between learning items or between learning and transfer items increases the task's cognitive cost increases as well. Aligning more distant items is more informative but cognitively more demanding because conceptual commonalities to be detected are less obvious and can only be done by children who's executive reasoning is sufficiently developed.

Search strategies explored with eye tracking measures. Whereas research has extensively studied factors that influence generalization performances, still little is known about strategies that lead to correct generalization.

To succeed in relational noun comparison and generalization tasks, children must successfully compare learning pairs and compare them with the stimuli that are provided as options (i.e., the generalization items). Analyzing eye movements thanks to eye tracking measures is a way of observing children's comparisons throughout a task, and all eye movements considered together are the trace of the child's solving strategy. This has already been done for example in an analogy task (Thibaut & French, 2016) or in an object noun generalization task (Stansbury et al., 2019).

In eye movements data, children's comparisons and search of a solution translate as switches between the task's items. Many different types of switches are possible between task items and theoretical framework is necessary to envisage their organization and analysis. Recent eye-tracking research on analogical reasoning tasks (another generalization task) investigated solving strategies and have confronted their data to two main hypotheses: the Projection-first and the Alignment-first strategies (Thibaut & French, 2016). Projection-first (Hummel & Holyoak, 1997) refers to an initial analysis of the learning domain, in search of a relation connecting items A and B. Once a relation is found it is projected on the generalization domain where item C must be matched to an item D so that A:B and C:D share the same relation. The Alignment-first strategy (Markman & Gentner, 1993) refers to the alignment of equivalent stimuli (i.e., that play the same role) in the learning and the generalization domains (in a scene, A with C, and B with D in a A:B::C:D proportional analogy).

In this study, we test 5-6 years old children on a relational noun comparison and generalization task adapted from Thibaut et al. (2018). Our main goal is to describe children's solving strategies and investigate the strategies as they are revealed by the temporal dynamics of the task, that is the temporal organization of the eye tracking data. We will investigate two things, the temporal dynamics of search strategies that led to correct answers and the temporal dynamics (and their differences if any exists) of strategies that led to errors.

We can consider the tasks switches following predictions mentioned above. At learning, two types of switches can be considered: 1. switches between items of a learning pair (e.g.: the watermelon and the knife), 2. switches between equivalent items from different pairs (e.g. the watermelon and the orange) (see Figure 1 for materials). Theoretically, the first translate relation extraction from a pair before relation projection, and the second translate pair comparison and equivalent learning item alignment.

At generalization, the switches that can be considered are: 1. the switches that are made between the generalization items themselves (e.g.: the paper and the given options, or between the options themselves) or 2. the switches made between equivalent learning items and generalization items (e.g.: the watermelon/orange and the paper, or the knives and the scissors). The first translate relation projection in the generalization items' domain, the second translate alignment between items with the same function in the learning domain and the generalization domain.

We hypothesized that switches between items of pairs at learning on the one hand and switches between the target entity and the generalization options (especially the relational match, the operator) on the other hand would confirm the Projection-first hypothesis. We hypothesized that switches between equivalent items in the learning pairs and switches between equivalent items from the learning and generalization domains (i.e., between operators, or between entities) would represent alignment and confirm the Alignment-first hypothesis. We will analyze data in order to assess whether switches are mainly between learning items and then between generalization items (projection first) or mainly between equivalent items in the learning and the generalization domains (alignment first).

In order to capture the time course of comparisons (i.e., switches between items) we divided each trial into three equal time slices. In this way, we may observe alignments or projections at different points in time. It will also reveal the general switches' organization during the task.

A second issue was whether conceptual distance would affect children's search strategies, that is the distribution of the switch types across the three time slices.

A third issue we address is the differences, if any, between strategies that led to correct answers or errors. The underlying question is: is it the strategy that determines success and if so, do differences appear on the onset of the trial or do they result from wrong decisions at the end of the trial once all options have been considered.

Methods

Participants

Seventy-six French speaking children were tested individually in a quiet room at their school. Participants were 5.5 years old (mean age = 65.8 months; range: 56 months to 74). Children were randomly assigned to one of the two experimental conditions (close comparison, 37 children or far comparison, 39 children). Informed consent was obtained from their school and their parents.

Materials

Fourteen experimental sets of pictures were built for the word generalization task, and four sets were built for the warm-up trials. Each set was associated to one of the seven relational categories used in the experiment (e.g., *cutter for, baby of, travel space for, food product of*), and was made of 14 pictures displaying one object each. Each set was composed of 3 learning pairs, and 2 test-subsets of 4 items. As mentioned above we manipulated the distance between learning pairs (close, far). All three learning pairs from a set showed the set's targeted relation (e.g. *cutter for*) and were composed of an entity (E) and an operator (O) (e.g. a watermelon as an entity and a knife as an operator). One of the three learning pairs was the standard learning pair (L), one was a pair conceptually close to the standard learning pair (Lc) and one was a pair conceptually further (Lf) from the standard learning pair than Lc. Thus, a *close learning* trial was built by showing L and Lc, and a *far learning* trial was built by showing L and Lf (see Figure 1).

We also manipulated generalization distance (near, distant). One of the two test-subsets was a near subset, and one was a distant subset. Each test-subset consisted of a GeneralizationEntity (GE), and three choices (Choices: Relational, Taxonomic and Thematic). The GE from the near test-subset was conceptually nearer to the standard learning entity than the GE from the distant test-subset. Thus, each participant saw 14 trials, 7 in the near generalization condition and 7 in the distant generalization condition.

Sixty-one students assessed semantic distance with similarity ratings. Ratings: close pairs (M = 6.15, SD = 0.68) vs. far pairs (M = 4.98, SD = 0.69), $t(26) = 4.47$, $p < .001$. The same was done to confirm that the near GE was conceptually nearer to the learning pairs than the distant GE was, ratings: near GE, (M = 4.51, SD = .71) vs. far GE, (M = 3.59, SD = 1.10), $t(26) = 2.64$, $p < .02$.

We used photos (500x500 pixels), displayed on a Tobii T120 eye-tracker device. The experiment was run with E-prime® software. Four different layouts were used to present the pictures on the screen to balance any effect of the picture's display. Learning pairs were either presented vertically (one above the other), or horizontally (next to each other). In both cases pairs were presented either left to right or right to left (i.e., layout 1, vertical-left to right; layout 2, vertical-right to left; layout 3, horizontal-left to right; layout 4, horizontal-right to left.

The design worked as follows. For each relational category, either the close or the far learning pairs were displayed and test pictures from the near or the distant test-subset were displayed opposite the learning pairs. Learning pictures and test pictures were separated by a fine black line (see Figure 1). Each learning pair was presented with a pseudo relational name for which we shaped 14 different bisyllabic labels (pseudo-words) which are, as shown by Gathercole and Baddeley (1993), easier to remember than monosyllabic pseudo-words (e.g., buxi, dajo, zatu, xanto, vira). Syllables were of the CV type which is the dominant word structure in French (from Lexique.org, New, Pallier, Brysbaert, & Ferrand, 2004)

Procedure

Task presentation and warn-up: When the children were settled in front of the computer with the experimenter, the task was presented as a game with a puppet, Yoshi. The puppet was used in order to make the task more attractive for children and to frame the use of non-existing names. The following instructions were given: "*Hello, we are going to play a game with Yoshi. Yoshi lives in a faraway country and speaks a special language. In this game we are going to play with words Yoshi uses for things. We are going to help him to sort some objects*." Children then saw four warm-up trials (identical to the test trials with the same instruction as detailed bellow) during which the experimenter first showed the items as they gave the instruction and progressively stopped hand movements.

Eye tracking calibration: the eye tracking device was calibrated with the Tobii device's calibration procedure. Two calibrations were done, one between the warn-up trials and the first test trial, and another between the 7th and 8th trial to reduce the amount of lost data due to children who move during the task.

Test: For each trial, all stimuli appeared on the screen and stayed in view until the end of the trial. The experimenter gave the following instruction (example in the case of stimuli illustrating the relation "*cutter for*" in the close learning - near generalization condition): "*Look! the big knife is the buxy for the watermelon. And the smaller knife is the buxy for the orange"*. In this way, the experimenter attracted the child's attention towards the screen with the word look but didn't indicate anything on the screen so that eye movements were not influenced. The experimenter continued: *"But look! the paper doesn't have a buxy. We need to find the buxy for the paper. Can you help Yoshi and show him which object is the buxy for the paper?*" This procedure was repeated for the 14 experimental relational categories. The rate of presentation of the learning pairs was automatically controlled. The presentation order and the items' positions on the screen were automatically randomly assigned. Labels were interchanged among pairs across participants.

Design

Children were randomly assigned to one of the two learning conditions (close comparison, 37 children; far comparison, 39 children). Learning distance (a between factor), was crossed with Transfer distance (near vs distant) a within factor.

Results

Performance data. To assess the effect of conceptual distance on children's generalization, we ran two analyses of variance (two-way ANOVAs) on the percentage of *correct* relational answers and on reaction times for correct answers with Learning distance (close, far) as a between-subjects factor and Generalization distance (near, distant) as a within-subject factor. These analyses did not reveal any significant effects. Indeed, children's percentages of correct answers (close learning: M_{Near} = 58.7 %, SD = 3.76 ; $M_{Distant}$ = 59.5 % , SD = 3.76 ; far learning: M_{Near} = 61.4 %, SD = 3.74 ; $M_{Distant}$ = 62.2 % , SD = 3.74) were equivalent in all conditions. Scores were all significantly above chance (at .33 because children choice between three choices). In previous studies, it has often been considered that an increase in conceptual distance between items makes the task more difficult, which explains the conceptual distance's effect on children's performance rates (Augier & Thibaut, 2013 for an example). Here, performance rates are high and equivalent in all distance conditions. Most likely, overall, the task was too easy in all conditions for there to be an effect of conceptual distance.

Coding and analysis of eye tracking data.

Given the lack of an effect of conceptual distance on children's performances we chose to exclude these factors from further analyses on eye-tracking data.

When considering eye tracking data, a switch was defined as a saccade between two items. Fifty-four different types of switches can be found with the present design. We grouped switches together (and averaged scores) that were equivalent following the theoretical framework mentioned above.

Learning switches were: switches between an entity and an operator from a learning pair (Entity-Operator) and switches between equivalent items from different pairs (Entity-Entity or Operator-Operator). Generalization switches were either switches between generalization items themselves (3 switch types: 1. GeneralizationEntity-Relational, 2. GeneralizationEntity-Distractors, 3. Between all choices); or switches between equivalent learning and generalization items (3 switch types: 1. Entities-GeneralizationEntity, 2. Operators-Relation, 3. Operators-Distractors; where "Entities" refers to LearningEntities and "Operators" refers to LearningOperators).

Each trial was cut into three equal time slices (see Thibaut & French, 2016 for rationale), and data was sorted by slice (1,2,3) before analysis. Slice is considered as a within factor. Interactions between switches and time slices are central to describe the search strategies' temporal dynamics.

We also considered trial accuracy (i.e.: correct answer and wrong answers) because different search strategy may determine accuracy. When analyzed, Accuracy (correct or false) is considered a within-subject factor.

Eye tracking data

First, we assessed switches at learning (i.e., between learning items). To assess whether children mainly extracted the relation from switches within a learning pair or aligned equivalent items from different learning pairs, we ran a two-way analysis of variance (ANOVA) on the proportion of learning switches for correct answers with Slice (1, 2, 3) and Switch type (Entity-Operator, Entity-Entity or Operator-Operator). As well as simple effects for slice (F(2,118) = 73.6 , p < .001 , η^2_P = .55) and switch type (F(1,59) = 149.4 , p < .001 , η^2_P = .72), the analysis revealed an interaction effect between Slice and Switch type, F(2,118) = 33.9 , p < .001 , η^2_P = .37 (Figure 2). A posteriori Tukey test showed that the proportion of Entity-Operator switches was significantly larger than Entity-Entity or Operator-Operator switches in the first two slices (slice 1: p < .001 ; slice 2: p < .001). In the first two slices children use comparisons between items from a same learning pair, that we interpret as switches to extract the targeted relation, and they do not align equivalent items between pairs during the task. In regard to the amount of Entity-Entity or Operator-Operator switches you consider that it is likely that they are merely due to children moving from a learning pair to another rather than due to alignment.

Figure 2 : Proportion of switches as a function of Slice (1, 2, 3) and Switch type (Entity-Operator, Entity-Entity or Operator-Operator). Error bars are SEM

Figure 3: Proportion of switches as a function of Slice (1, 2, 3) and Switch type (GeneralizationEntity-Relation, GeneralizationEntity-Distractors, Between all choices; Entities-GeneralizationEntity, Operators-Relation, Operators-Distractors).
Error bars are SEM.
Note: Switches within the generalization domain (reflecting projection) are full, and switches between the learning and the generalization domains (reflecting alignment) are checked)

Second, we assessed switches for generalization. To analyze children's search in the generalization domain we ran a two-way analysis of variance (ANOVA) on the proportion of switches for correct answers with Slice (1, 2, 3) and Switch type as within factors. Switch types were switches between items within the generalization domain: GeneralizationEntity-Relation, GeneralizationEntity-Distractors, Between all choices; and switches between equivalent items in the learning and the generalization domains: Entities-GeneralizationEntity, Operators-Relation, Operators-Distractors.

As well as simple effects for slice ($F(2,118) = 120.0$, $p < .001$, $\eta^2_P = .67$) and switch type ($F(5,295) = 142.2$, $p < .001$, $\eta^2_P = .71$), the analysis revealed an interaction effect between Slice and Switch type, $F(10,590) = 36.6$, $p < .001$, $\eta^2_P = .38$ (Figure 3).

The interaction shows that children switch between items in the generalization domain (GeneralizationEntity-Relation, GeneralizationEntity-Distractors, Between all choices: full columns in Figure 3) and not between equivalent items in the learning and generalization domains (Entities-GeneralizationEntity, Operators-Relation, Operators-Distractors, checked columns in Figure 3). A posteriori Tukey test also showed that the proportion of GeneralizationEntity-Relation switches is significantly larger than the proportion of GeneralizationEntity-Distractors switches in the last slice ($p < .001$).

This analysis, combined with the previous analysis of the switches at learning, reveals that children do not align equivalent items from the learning and the generalization domains. They search in both domains to find a match for the GeneralizationEntity and progressively increase switches from the GeneralizationEntity to the Relational choice until their choice at the end of the trial. They make this search, unexpectedly in both domains from the beginning of the task even though they don't align items from the different domains. The very few switches translating alignment may simply reflect children passing from the learning domain to the generalization domain but not alignment.

A second issue was the difference between strategies of trials that led to correct or wrong answers. To analyze this question, we ran a three-way analysis of variance (ANOVA) on the proportion of switches with Accuracy (correct, false), Slice (1, 2, 3) and Switch type (Entity-Entity or Operator-Operator, Entity-Operator, GeneralizationEntity-Relation, GeneralizationEntity-Distractors, Between all choices) as within-subject factors. The analysis revealed effects of all factors. The most interesting effect for this study was the interaction between Accuracy, Slice and Switch type: $F(20,1060) = 11.22$, $p < .001$, $\eta^2_P = .18$. (Figure 4). The interaction and a posteriori Tukey analysis revealed that search profiles are identical at the beginning for both types of trials and that the major difference between errors and correct answers is at the end of the trial between the relational choice and the distractors. Another interesting observation is that even for errors children had switches between choices at the end of the trial which suggests that they were checking their answer. These two results strongly suggest that children followed the same strategy in both types of trials but ended up with the incorrect solution.

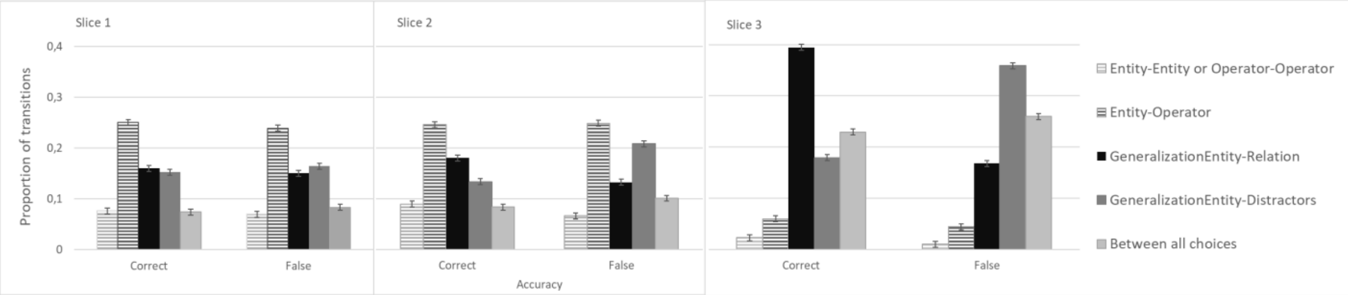


Figure 4: Proportion of switches as a function of Accuracy (Correct, False), Slice (1, 2, 3) and Switch type Error bars are SEM.

Note: Learning switches are lined, generalization switches are full.

Discussion

Our main interest in this study was solving strategies' temporal dynamics in a relational noun comparison and generalization task. We hypothesized that solving strategies, would follow Projection-first predictions (Hummel & Holyoak, 1997) or Alignment-first predictions (Markman & Gentner, 1993) or would be a combination of both.

Switch analysis revealed that children's strategies follow predictions from the Projection-first hypothesis. Children clearly systematically explore the task's items from the beginning (they make learning switches and switches between generalization items themselves from the beginning of the task) and check their answer at the end of the task before answering.).

Fixation times reveal that children organize this search around the GeneralizationEntity, around which they pay more attention to the learning items at first, then progressively turn their attention to the generalization items. This organization of fixation times witnesses a constructive view of the solution discovery: first, find a relation with the learning pairs, then apply it to the other domain (Bethell-Fox et al., 1984

The analysis of the differences between strategies that lead to correct answers or errors reveals that the major difference between correct and error strategies holds in the children's decision making at the end of the trial.

These results are interesting for different reasons. First very few switches translating alignment were found whereas these comparisons are well known to help generalization. However, children are old (5 years) compared to previous studies and more alignment may be found in younger children that need more comparing and aligning to succeed. If it was the case, it may be that children developpe towards projection first strategies as they grow up. Second, children seem to progressively build their representation of the relation thanks to all the comparisons they make rather than only from the learning pairs. Third, the analysis of fixation times reveals a profile that is very similar to Thibaut and French's (2016) results in the domain of analogical reasoning. These authors observed that 5-years old children organized their search around the C term, the item for which one has to find a D term, which would terminate the analogy in a relationally consistent way.

Finally, following a projection-first strategy, irrespectively from success or failure to extend the built relational concept leads to a provisional conclusion. Although children identified this strategy as the optimal way to learn the meaning of new relational words in comparison setting, this is not the sole determinant to succeed when they have to find a relational match.

Our data are important because, first, they provide the first online analysis of the time course of generalization and, second, suggest that a strategy seems to dominate their exploration: first understanding the relation within each pair, second applying it to another domain by systematically comparing the different options with the entity, and last controlling the different options in terms of soundness.

Beyond our data, continuity between the progressive construction of representation and decision making is probably driven by individual factors (e.g., cognitive control, goal maintenance, interference resistance) which should be investigated in further studies.

To conclude, generalization of relational concepts is the most relevant aspect of conceptual development for educational outcomes (Goldwater & Schalk, 2016). Identifying children's strategies to generalize relational concepts could be quite important to develop methods to specifically improve this kind of conceptual learning/reasoning. Further studies are now needed to test different age groups and get a better understanding of how children's strategies develop over time.

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