Show me, don't teach me: Active exploration promotes children's relational reasoning

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Abstract

Young children often struggle with reasoning based on abstract relations, which is crucial for learning and thinking. Research has shown that children's relational reasoning abilities can be enhanced under certain circumstances. The underlying reasons and mechanisms behind such enhancement, however, remain unclear. This study examined the effectiveness of explanation, a recently discovered method, in enhancing children's relational reasoning abilities. Seventy-one 4- and 5-year-old children participated in a modified Relational Match to Sample (RMTS) task. Some children interacted with an experimenter who demonstrated relational matches and engaged in question-answer sessions, while others completed the task without such interactions. Results indicated that children who observed demonstrations and provided explanations or reports showed a higher proportion of relational matches compared to those who completed the task without such interactions. Furthermore, explanation was more effective than report in promoting children's relational reasoning. These findings suggest that interactive experiences that encourage exploration contribute to the development of children's relational reasoning abilities.

Keywords: cognitive development; relational reasoning; exploratory learning; explanation

Introduction

Relational reasoning is the ability to recognize and transfer shared patterns between two events or situations (Holyoak & Lu, 2021). It plays a crucial role in human cognition and is instrumental in problem-solving, concept acquisition, and academic accomplishments, particularly in the domains of mathematics and science (Gentner et al., 2011; Goldwater & Schalk, 2016). For example, the determination of the molecular structure of benzene posed a challenge in the past due to its insufficient number of atoms to form a stable structure. However, the chemist Kekulé had a dream that inspired him with a snake analogy. In his dream, a snake bit its own tail, forming a circle. This imagery sparked an idea in his mind: just as a straight snake can transform into a circle, a carbon chain can also adopt a circular form. Such relational thinking led Kekulé to realize that the benzene molecule is, in fact, structured as a hexagonal ring.

However, young children often struggle with relational reasoning, as they tend to initially prioritize focusing on object features rather than abstract relationships. For instance, when children are presented with a card displaying two squares (relation: same) and are asked to select a card that matches it, they tend to choose the card that also features a square rather than the one with two circles. Adults, in contrast, would choose the card with two circles. It has been demonstrated that children's relational reasoning could be promoted in some situations. For example, using language labels (Christie & Gentner, 2014), making comparisons (Anderson et al., 2018; Gentner et al., 2011; Thibaut & Witt, 2023), and inducing relational thinking (Walker et al., 2018) have all been shown to promote children's relational reasoning. Nevertheless, the mechanisms and underlying reasons behind these successes remain inadequately understood. Additionally, it is crucial to gain a comprehensive understanding of how interventions can be universally applied to promote relational thinking in both educational and everyday contexts.

Young children prefer perceptual similarity over abstract relations in reasoning

Preverbal infants show the ability to recognize and utilize abstract relationships. However, they may encounter difficulties in relational reasoning when confronted with objects that are perceptually similar. Previous studies showed that infants between 3 and 9 months old could perceive the *same* and *different* relations. They exhibited longer visual attention towards novel pairs of objects that deviate from the familiar relation (Ferry et al., 2015). Toddlers as young as 18-30 months can successfully complete a causal relational reasoning task. Upon witnessing the demonstration that two *same* or *different* blocks could activate a music box, children were able to successfully activate the music box using other blocks (Walker & Gopnik, 2013). Nevertheless, young children aged 4 and 5 years may have difficulty in using relations in their reasoning. In a typical Relational Match to Sample (RMTS) task, children were presented with three pairs of objects: a target pair (e.g., two circles), a relational matching pair (e.g., two squares), and an object matching pair (e.g., a circle, and a triangle). They were required to determine whether the relational pair or the object pair is a match to the target pair. Results showed that 4.5-year-olds typically chose the object matching pair rather than the relational matching pair (Christie & Gentner, 2007).

The failure of children on the RMTS task may stem from their specific inductive biases, which refer to their inclination to prioritize similarities based on objects rather than relational similarities (Brockbank et al., 2022). This bias may lead to children's failure in the graphic RMTS task in two ways. Firstly, with the bias, children may have difficulty in identifying relations between objects, especially when the two graphics have no apparent connection. Secondly, children struggle to use relations because they do not perceive that they can rely on relations to guide their reasoning (Walker et al., 2016). Therefore, one solution to facilitate children's relational reasoning is to help them overcome specific induction bias.

Approaches to promote children's relational reasoning

One effective approach to facilitate children's relational reasoning is to provide additional materials to emphasize abstract relations while diminishing perceptual similarity. For instance, researchers have utilized techniques such as providing labels for object pairs (Christie & Gentner, 2014) or introducing additional object pairs to emphasize shared patterns (Anderson et al., 2018; Gentner et al., 2011; Namy & Gentner, 2002; Thibaut & Witt, 2023). Another approach involves using training methods that emphasize abstract relations to induce children's relational thinking (Walker et al., 2018). For example, studies have shown that after completing training in size or number rather than shape and color matching, children showed increased relational matches in the graphic RMTS task (Kroupin & Carey, 2021).

Recently, a study found that children were able to overcome inductive biases without additional materials. Rather, a novel and effective method was reported that prompting 5- and 6-year-old children to explain facilitated their relational reasoning (Brockbank et al., 2022). In a graphic RMTS task, both children and experimenters took turns making selections. The experimenter served as a pedagogical model by consistently making relational matches. Some children were asked to explain their choice or the experimenter's choice, while others were asked to report their own choice or the experimenter's choice. The results indicated that children who were prompted to explain showed a higher proportion of relational choice compared to those who were asked to simply report, suggesting that asking children to explain enhance children's using of relations during their reasoning.

Active exploration may support children's relational reasoning

Why would asking children to explain promote their relational reasoning? One possible account is that when children are asked "why", they consider more possibilities beyond perceptual similarity. They generate hypotheses and tend to prefer those were more abstract and generalizable (Csibra & Gergely, 2009). Another possible account posits that explanation is a creative process that requires children to generate and output new content (Chi, 2009). This creative process plays a significant role in fostering children's abstract thinking. Both possible accounts emphasize the importance of children's active exploration in abstract thinking.

The discovery learning theory, also known as constructivism, proposes that children primarily learn through their own active exploration of the environment (Bonawitz et al., 2011). During this exploratory process, children naturally generate hypotheses and actively seek explanatory information (Gopnik, 2020). For instance, even at the age of 3, children readily ask and answer "why" questions to seek explanations for observable facts and to expand their understanding of the world (Hickling & Wellman, 2001).

It is important to note that children's active exploration is influenced by the ways in which they interact with adults. Interaction styles that support children's exploration are more beneficial for their thinking and discovery, such as asking them open-ended questions or providing incomplete or unreliable information (Lohse et al., 2022). For example, in a toy exploration task, when adults acted ignorant about the toys, children engaged in longer and more extensive explorations, leading to the discovery of additional functions of the toy. On the other hand, when adults acted that they well-know about this kind of toy, children exhibited less exploration (Bonawitz et al., 2011). In the same way, teaching or instruction often limits children's exploration and may not adequately support their abstract thinking.

Therefore, we consider that children's active exploration plays an important role in their abstract thinking and relational reasoning. Specifically, the pedagogical demonstration conducted by an experimenter highlights the discrepancy between the demonstration and children's own opinions (their specific bias), inspiring their desire to explore. Children often perceive adults' utterances as credible information during interactions and adjust their own behavior accordingly (Lohse et al., 2022). Moreover, asking children questions (explain or report) encourages them to actively explore and generate hypotheses. Therefore, we anticipate that children who watch instructional demonstrations and are asked to explain or report will exhibit more relational matches in the RMTS task compared to those who complete the task individually.

In addition, we consider that asking children to explain have a unique and more effective impact on children's abstract thinking than report. Because asking children questions that require them to generate explanations has been shown to effectively foster children's exploratory behavior (Bonawitz et al., 2012; Fisher et al., 2013; Yu et al., 2018). On the contrary, asking children to *report* may constrain the process of their exploration and impede their ability to generate hypotheses for understanding the current task.

Additionally, generating and verbalizing explanations aids in remembering relations (Fivush et al., 2011), which is essential for using them to inform reasoning.

In sum, we hypothesize that the combination of pedagogical demonstration and explanation/report, as a method to evoke children's active exploration, has the potential to enhance children's relational reasoning and that explanation may have a stronger effect than report, resulting in a higher proportion of relational choices.

The present study

This study aims to investigate the effects of combining pedagogical demonstration with explanation/report on children's relational reasoning on familiar categorical and thematic concepts. Previous research showed that children were sensitive to materials in graphic RMTS tasks. For example, using less salient and familiar graphics can enhance children's relational choice (Christie & Gentner, 2014; Hochmann et al., 2017; Son et al., 2011). Therefore, in this study, we used familiar objects with rich characteristics and studied two types of relations that are common in real-life scenarios: categorical and thematic relations. Our study addresses two key questions: Firstly, it helps to clarify the significance of children's active exploration in promoting their abstract thinking. Secondly, it contributes to investigate whether the effect of explanation remains consistent and can transcend variations in materials used.

The task and procedure were similar to Brockbank et al. (2022). There were three conditions: baseline, explanation, and report. In the explanation and report conditions, children and the experimenter took turns in completing a matching task. Children were asked to provide explanations or reports regarding the experimenter's choices or their own choices. In the baseline, children completed the matching task individually. Consequently, there was no involvement of the experimenter's choices or question-answer sessions in the baseline group. No corrective feedback was provided in any of the three conditions. We predicted that children in the explanation or report condition would have more relational matches than those in the baseline. Moreover, explanation would have a stronger effect on promoting children's relational reasoning than report, with children in the explanation condition exhibiting enhanced performance in identifying relations and demonstrating a greater extent to rely on relations in their reasoning.

Methods

Participants

The previous experiment on explanation and report (Brockbank et al., 2022) yielded an effect size of 0.63 for the effect of groups on children's selection. A sample size of 51 would provide a power of 0.98 to detect such an effect in the case of three groups (Faul et al., 2007). Allowing for potential participant exclusion, we recruited seventy-one 4- and 5-year-olds (*M* = 62.69 months; *SD* = 5.74, range 51.16–71.47; 23 girls and 48 boys) to participate this study. Children were recruited from a public kindergarten in Zhuhai, Guangdong Province, China, and they were randomly assigned to one of three conditions (baseline, explanation, and report). The three groups consisted of 23, 22, and 26 children, respectively. All groups had similar age (baseline: range 51.55–71.47, *M* = 60.44; explanation: range 52.21–71.01, *M* = 64.21; report: range 51.16–70.36, *M* = 63.39; *p* = .063). Three additional children were excluded due to experimenter error (the experimenter provided positive or negative feedback).

Materials

Thirty-two distinct triads were used, with each triad comprising three 1.8” × 3.4” white cards. These cards contained pairs of color pictures representing different familiar objects (e.g., an apple, scissors). Each triad consisted of a target card, an object match card, and a relational match card (see Figure 1). Half of the target cards (16) presented the relation *same category* (e.g., an apple and a pineapple). Four categories that are familiar to children were involved: fruits, vegetables, insects, and mammals. Half of the target cards presented the relation *same theme* (e.g., a panda and bamboo). Four themes that are also familiar to children were involved: eating, cutting, producing, containing. Each category or theme possessed 4 triads.

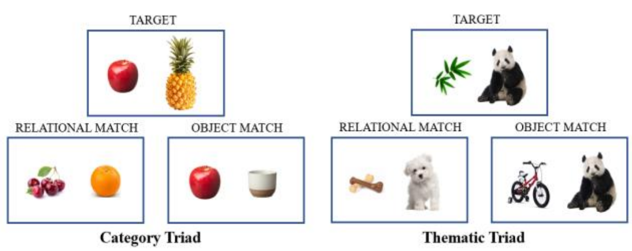

Figure 1: Sample triads of category and thematic relations. A triad includes a target, a relational match, and an object match.

For the target cards with *same category* relation (e.g., an apple and a pineapple), the object match cards included an object that appeared in the target (e.g., an apple) and an object belongs to different categories with the target (e.g., a cup). The relational match cards included two unique objects that belong to the same category with the target (e.g., cherries and an orange). For the target cards with *same thematic* relation (e.g., a panda and bamboo), the object match cards included an object that appeared in the target (e.g., a panda) and an object which had different thematic relation with another object (e.g., a bicycle). The relational match cards included two other objects with the same thematic relationship to the target (e.g., a dog and bones). The objects that were shared between the target card and the object match card always appeared in the same location on the card. For instance, the panda appeared on the right side of the card, regardless of whether it was a target card or an object match card. Object match cards and relational match cards were randomly placed on the left or right side below the target cards. Each card only appeared once.

Children in the explanation and report groups were exposed to all 32 triads, with half of them being completed by the experimenter and the other half being completed by the children themselves. The same 16 triads were also exposed to children in the baseline group. All children were initially presented with the category-relation triad, followed by the thematic-relation triad. The triads were presented in a fixed order, and all children were exposed to them in the same sequence. Additionally, two additional category-relation triads (birds) were used for practice before the formal experiment began.

Procedure

In a quiet room in the kindergarten, a child and experimenter sat across a table from each other. Under the explanation and report conditions, the experimenter invited the children to take turns playing a matching game, with the experimenter starting first. In the first two triads (T1 and T2), the experimenter placed the target card in front of the children and said, "See this card". Then, the experimenter placed the object and relational match cards on the table below the target and said, "Now, see these two cards". To ensure that children comprehended the current task and were adequately engaged, a question was posed. "Now the question is, which of these two cards (pointing to the object and relational matches) matches this one (pointing to the target card)?" No matter what response the child made, the experimenter made a relational match choice by saying "in my game, this card (pointing to the relational match) matches this card (putting the relational match card together with the target card)!".

Children in the explanation group were prompted to explain the experimenter's selection by being asked, "Can you tell me why I said this card (pointing the relational match card) matches this card (pointing the target card)?". In the report group, children were asked, "Can you remind me which card I said matches this card (pointing to the target)?". Their responses were recorded. No feedback or additional information was provided to the children, even if their explanations were uninformative or unrelated to the task. Afterward, all three cards in a triad were removed from table.

In the following two triads (T3 and T4), children were told, "Now, it's your turn to play my game!". The experimenter placed a triad of cards on the table, following the same procedure as before. Children were required to select a card that match the target card from the object match card and relational match card. They were asked, "Can you tell me which of these cards (pointing to the object match and the relational match) matches this card (pointing to the target)?". Children's responses were recorded. No feedback was given on their selection. After making their choice, children in the explanation group were prompted to explain themselves selection by being asked, "Can you tell me why you said that this card (pointing to the child's selection) matches this card (pointing to the target)?". Those in the report group need to report their selection again by being asked, "Can you remind me which card you said matches this card (pointing to the target)?".

After T3 and T4, the experimenter resumed their turn for T5 and T6. This alternating pattern between the experimenter and the child continued for a total of 32 trials. As a result, each child provided a total of 32 explanations or reports (16 for the experimenter's selections and 16 for their own selections). Throughout the game, a total of 16 matches were generated by children, which served as the dependent variable.

In the baseline group, children also generated 16 matches using the same materials. They were told that it was a card matching game. The experimenter presented the cards in the same manner as described earlier and asked, "Can you tell me which of these cards (pointing to the object match and the relational match) matches this card (pointing to the target)?". Children made their own selections and did not receive any corrective feedback throughout the 16 triads. Their selections were recorded.

Coding

In each triad, we recorded the children's selections. For matching questions, children's relational match selections were coded as "1", and their object match selections were coded as "0". As a result, each child got a matching score between 0 and 16.

To observe children's matching preference, we quartered their matching scores and divided them as definite relational preference, ambiguous preference, and definite object preference. Matching scores above 12 were considered *definite relational preference*, while those below 4 were considered *definite object preference*. Matching scores between 4 and 12 were defined as *ambiguous preference*.

Results

Because the effect of relational type (i.e., category vs. thematic) was not significant (p = .540) and did not interact with the group (p = .814), the data were collapsed across two relational types. Figure 2a shows the proportion of relational matches made by children in the baseline, explanation, and report groups. Figure 2b illustrates the proportion of children's relational matches across trials. The proportions of relational matches on two adjacent trials were averaged and presented, thus illustrating the children's proportion of relational matches to the same categorical or thematic relation (e.g., Trials 1 and 2 are both associated with matches on the *vegetable* category, while Trials 9 and 10 are both related to *eating* theme).

Children's total matching scores (out of 16) were significantly different among groups, F (2, 68) = 6.92, p = .002. As we predicted, children in explanation and report groups had more relational matches than those in the baseline group (baseline: M = 5.13, SD = 5.40; explanation: M = 10.91, SD = 5.81; report: M = 9.38, SD = 5.14). No significant difference was found between the children in report and explanation groups, p = .337.

One-sample *t*-test compared children's matching score with chance level (8) to reveal children's matching preference. Results showed that children in the explanation group significantly preferred the relational match, t (1, 21) = 2.35, p = .029, 95% CI = [.34 5.48]. Children in baseline group significantly preferred the object match, t (1, 22) = -2.55, p = .018, 95% CI = [-5.21 -.53]. As for children in the report group, no significant difference was found between their matching scores and chance level, t (1, 25) = 1.37, p = .182, 95% CI = [-.69 3.46].

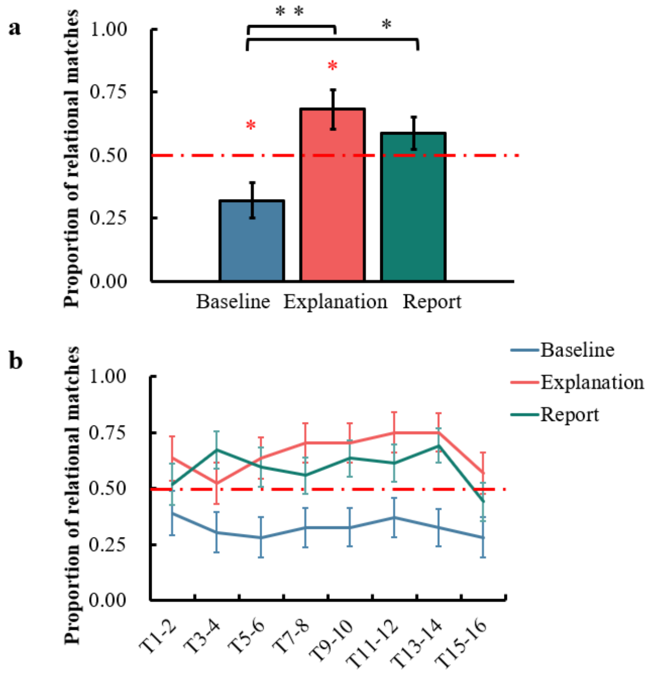

Figure 2: Proportion of children's relational matches in groups (a), and the proportions across trials (b). *T1-2* means the average proportions of Trial 1 and 2. The chance level is 0.5. Error bars represent standard errors of mean.

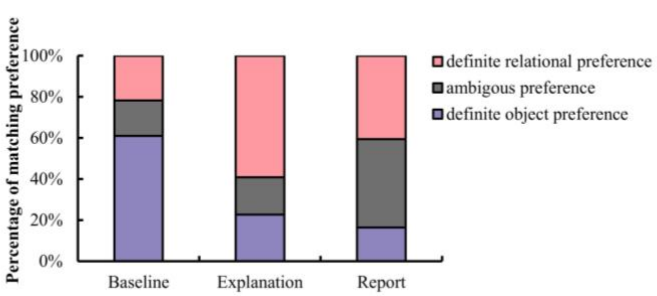

Figure 3: Percentage of matching preference in the baseline, explanation, and report groups.

Furthermore, we compared children's matching preference across three groups. As shown in Figure 3, children exhibited significantly different matching preferences among three groups, $\chi 2$ (4) = 20.87, p < .001. Compared to the baseline, explanation and report were effective in promoting children's preference for using relations. Specifically, children in the explanation group showed low definite-object preference and high definite-relational preference, $\chi 2$ (2) = 9.80, p = .007. Similarly, children in the report group also showed low definite-object preference, whereas their ambiguous preference rather than definite-relational preference was high, $\chi 2$ (2) = 11.32, p = .003. In addition, more children in the report group tended to hold an ambiguous preference than in the explanation group (explanation: 18.2%; report: 40.3%), $\chi 2$ (2) = 5.56, p = .062.

Discussion

In the current experiment, children who were engaged in the active exploration through interaction with the experimenter exhibited more relational matches in a RMTS task, compared to children who completed the task with minimal interaction and exploration. Specifically, children who observed the demonstration and provided explanations or reports were more likely to discover and utilize abstract categorical or thematic relations. Furthermore, in line with our predictions, children who generated explanations exhibited a greater preference for using relations in their reasoning compared to those who provided reports. These findings suggest that the children's active exploration could effectively promote their abstract thinking. The interaction way that encourages children to active explore, such as asking them to explain, yields better effect.

The way interaction works might involve two steps. First, the experimenter's demonstration created conflicts with children's own opinions, thereby arousing children's desire of exploration. Findings from developmental psychology and linguistics suggest that incomplete or unreliable information provided by adults encourages children's further thinking and exploring behavior (Lohse et al., 2022). The second step involves questioning children to support them in generating hypotheses. Asking them to explain is more helpful than asking them to report in this regard. Previous research has provided evidence that asking children questions, particularly questions that require explanations, is beneficial for them to generate more hypotheses in order to understand observable facts and expand their knowledge about the world (Hickling & Wellman, 2001; Yu et al., 2018). Adult questioning has even been found to be positively related to children's memory of past events (Fivush et al., 2011). On the other hand, asking children to simply report their observations may constrain the range of hypotheses they consider. Because they may assume that there is no need to explore further possibilities. As the results showed that although the children in the report group showed a notable improvement in relational matches compared to those in the baseline group, their performance did not exceed the chance level to the same extent as the children in the explain group.

Another possibility that interaction facilitates children's relational reasoning needs to be discussed—imitation. It is possible that children made more relational choices by imitating the experimenter's choices. However, our results do not support this possibility. Specifically, in the RMTS task, there was a simple rule for children to imitate—selecting the card without the same object as the target card. This rule is easily discernible by children due to their preference for objects. If children's strategy is imitation, they should have similar relational matches in both explanation and report groups. Nevertheless, our results showed that children under the explanation group had a significantly higher proportion of relational matches than chance level. In contrast, the proportion of children in the report group was not significantly higher than chance level. Additionally, children in the report group showed an ambiguous preference between relational and object matches, whereas those in the explanation group displayed a clear preference for relational matches. These findings suggest that imitation alone does not explain the observed differences in relational reasoning between the two groups.

Different from Brockbank et al. (2022), our study found that asking young children to report also promoted their relational reasoning. Specifically, children in the report group had a significant higher proportion of relational matches than those in the baseline group. The discrepancy in findings between the two studies could primarily be attributed to the utilization of different materials. In the current study, we used objects which are familiar to children (e.g., an apple, a panda). Research has indicated that children's familiarity with materials can influence their inductive reasoning. Children show the ability to reason based on category at an earlier age when presented with familiar materials compared to unfamiliar materials (reviewed in Fisher et al., 2015; Long et al., 2012). Moreover, the categorical and thematic relations used in this study are common in real-life scenarios, which may make children willing to use them when reasoning. Therefore, it may be easier for children to discover and utilize relations with familiar materials and relations. Therefore, when children in the report group interacted with the experimenter and had abundant time to explore the materials, they made more relational matches than object matches. Additionally, familiar materials and common relations may enhance the impact of demonstrations, as children may be more capable to comprehend the reason behind the experimenter's relational matches.

In addition, cultural contexts could also be one of the reasons for the difference in the results of the two studies. There is no direct evidence indicating variations between Eastern and Western children in their performance on RMTS tasks. However, Carstensen et al. (2019) suggested that Chinese children showed an early tendency to prioritize abstract relations compared to US children. Although our study did not find evidence of Chinese children prioritizing abstract relations, as indicated by the significant low proportion of relational matches in the baseline group, it is possible that the effect of demonstration and report would be strengthened in Chinese children due to the cultural factors. Further research is necessary to explore the influence of cultural context on children's abstract thinking.

To better understand the mechanisms of adult-child interactions and the effects of asking children to explain, further research could explore the following questions. Are there any factors that may constrain the effect of interaction and explanation on facilitating young children's abstract reasoning? For example, factors like task difficulty, types of materials, and the role of adults who interact with children (e.g., teacher, parent, or others). Moreover, do interaction and explanation enhance children's overall abstract reasoning abilities or primarily change their performance on specific tasks? In other words, it is necessary to explore whether the facilitative effect of interaction and explanation on young children's abstract reasoning can be retained over time and transferred to different situations.

In conclusion, these findings provide compelling evidence that children's active exploration pave the way for their abstract thinking. Interactive approaches between adults and children that encourage and support children's active exploration, such as asking them *why* questions, are particularly effective.

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