Zheng, Y. & Gentner, D. (2025). Comparison helps children form broad explanations. *Proceedings of the 47th Annual Meeting of the Cognitive Science Society.*

Comparison Helps Children Form Broad Explanations

Yinyuan Zheng[1] (zhengyinyuan@u.northwestern.edu)
Dedre Gentner[1] (gentner@northwester.edu)
[1]Department of Psychology, Northwestern University
2029 N. Sheridan Rd., Evanston, IL 60208-2710 USA

Abstract

Research has shown that generating explanations can benefit learning in both children and adults. In part this is because people prefer explanations that characterize phenomena in terms of broad regularities. Here we propose that comparison is integral to the process of generating broad, satisfactory explanations. Specifically, (1) generating explanations often invokes comparison, (2) the resulting structural alignment process reveals commonalities that feed into a broad explanation. In Experiment 1a, we adapted a study on explanation-generation by Walker et al. (2017). 5- and 6-year-old children were asked to explain a set of outcomes that could result either from a single broad cause or from two or more specific causes. When children had the opportunity to compare the outcomes, they arrived at the broad explanation, replicating Walker et al. When comparison was made difficult, children preferred specific explanations. The results suggest that comparison is integral to the power of self-explanation. In Experiment 1b, we found that comparison by itself was not sufficient to lead children to broad explanations—suggesting that both explanation and comparison are critical in allowing children to attend to the broad pattern.

Keywords: Comparison; Structural Alignment; Explanation; Causal Reasoning; Cognitive Development

Introduction

Extensive research has shown that generating explanations can be instrumental to learning (Bisra et al., 2018; Chi et al., 1989, 1994; Muldner, Burleson, & Chi, 2014; Lombrozo, 2016; Nokes-Malach et al., 2013; Rittle-Johnson, 2006; Rittle-Johnson, Loehr, & Durkin, 2017; Walker et al., 2014; Walker & Lombrozo, 2017). Specifically, studies have revealed that when people engage in explanation-seeking, they prefer explanations that invoke broad, generalizable regularities (Legare, Sobel, & Callanan, 2017; Lombrozo, 2006; Williams & Lombrozo, 2010; Walker & Lombrozo, 2017). These explanatory preferences benefit learning and transfer by focusing children on deep relational knowledge and causal properties (Busch, Willard, & Legare, 2018; Lombrozo, 2016; Walker et al., 2014). This raises a key question—how does explaining lead learners to discover broad patterns? We suggest that one key process invoked during explanation is comparison, and that comparison helps explainers identify broad patterns through highlighting commonalities. Before presenting evidence, we first briefly review the literature on the learning benefits of explanation generation.

The Learning Benefits of Explanation Generation

In a classic set of studies, Chi and colleagues showed that engaging in self-explanation—where learners explain to themselves instead of receiving answers from others—can help students grasp difficult science concepts (Chi et al., 1989, 1994; Chi, 2013). For example, Chi et al (1994) asked eighth graders either to self-explain a passage on the human circulatory system or to read the passage twice. The self-explanation group showed a deeper understanding of the topic than the reading group, particularly on inference questions that required generating new knowledge. Since then, much fruitful research has demonstrated the benefit of generating explanations. For example, Legare and Lombrozo (2014) showed 3- to 5-year-old children a set of gears that could be arranged to turn a fan. Half the children merely observed the demonstration while the other half were asked to explain how it worked. During testing, children were first asked to repair the same machine that was missing a gear and then to construct a new one. Children in the explanation group were more successful in both fixing the machine and constructing their own machines than those in the description group. This suggests that explaining can foster children's discovery of nonobvious causal pattern (Busch, Willard & Legare, 2018; Callanan & Oakes, 1992; Keil, 2006; Legare, Sobel & Callanan, 2017; Lombrozo, 2006).

One mechanism through which explanation generation benefits learning is people's explanatory preference. According to Lombrozo's *subsumptive constraint* account, people prefer explanations that characterize things in terms of broad, general patterns and that this has important implications for how we reason and learn (Lombrozo, 2006; Lombrozo & Carey, 2006; Williams & Lombrozo, 2010). This account proposes that a key property of explanation is to favor generalization—that is, to discover that a specific event can be subsumed under a general pattern that also accounts for other cases. People find such explanations informative and therefore satisfying. Consequently, when constructing explanations themselves, people will search for an explanation that reveals a broader pattern. In short, the act of explaining can lead learners to seek broad regularities rather than context-specific accounts.

To test this claim, Williams and Lombrozo (2010) presented people with two groups of artificial robots. The categories were designed such that most of the members within each category shared a highly salient feature (body shape), but all of the members in a group shared a less salient property (foot shape). Specifically, the four 'Glorps' all shared the subtle feature of pointy feet but only three of them had a round body; in contrast, the four 'Drents' all shared the subtle feature of flat feet but only three had a square body. Thus, body shape constituted an imperfect, albeit salient, rule with a 75% success rate, whereas foot shape was a less obvious 100% rule that best divided the robots. When people were asked to explain why each robot was of its category, they were more likely to identify the 100% rule than when not explaining. These findings support Lombrozo's claim that engaging in explanation-seeking drives a search for unifying broad patterns. Similar results have been found for children (Walker, Bonawitz, & Lombrozo, 2017; Walker & Lombrozo, 2017). Given the effectiveness of explanation in early learning, it is critical to understand what mechanisms support its success.

The Role of Comparison in Explanation

How do people arrive at a broad explanation? Sometimes the relevant knowledge can simply be retrieved—for example, when applying a familiar conceptual framework to explain new cases. But often a broad pattern needs to be identified on the spot. We suggest that analogical comparison is one key mechanism that allows learners to arrive at broad patterns.

The idea that comparison is implicated in generating explanations has received some support (Chin-Parker & Bradner, 2010, 2017; Hilton & Slugoski, 1986; Hoyos & Gentner, 2017; Landy & Hummel, 2010; Sidney, Hattikudur, & Alibali, 2015). According to structure-mapping theory, comparison entails a process of structural alignment in which like relations are aligned and objects are placed into correspondence based on having like roles within the common relational structure (Forbus et al., 2017; Gentner, 1983, 2010). The mapping process can render more salient common relational structure and alignable differences—differences that play corresponding roles in the aligned structure (Gentner, 2003, 2010; Markman & Gentner, 1993).

We propose that comparison contributes to explanations by revealing potentially relevant commonalities. Through the alignment process, learners can come to notice common relational structures beyond the salient surface details. This fosters knowledge abstraction, in which a general idea is formed over specific instances (Chen, 1999; Christie & Gentner, 2010; Dixon & Bangert, 2004; Gick & Holyoak, 1983; Loewenstein, Thompson, & Gentner, 2003; Markman & Gentner, 1993; Thompson & Opfer, 2010). Commonalities are likely to be broader in scope than are features of individual cases, since they (by definition) depict a shared characteristic. By attending to the commonalities, learners can construct an explanation that satisfies the need for breadth. In sum, we propose (1) that generating explanations often invokes comparison, and (2) that the comparison process highlights important commonalities (and sometimes differences) that provide the basis for broad explanations.

Edwards et al. (2019) showed evidence for the role of comparison in explanation success. They presented people with the two robot categories used by Williams and Lombrozo (2010). Again, the robots could be differentiated using a 75% accurate salient feature (i.e., body shape) or a 100% accurate, less obvious property (foot shape). Half the participants were asked to explain why a robot (or robots) belonged to one category or the other. The other half were asked to compare pairs or groups of robots, either within-category or between-category or both. The results underlined the effectiveness of explanation-generation: participants in the explanation conditions were more likely to discover the 100% rule than those in the comparison conditions.

However, participants' self-reports revealed a telling pattern. As expected, people in the explanation condition reported engaging in more explanation than did those in the comparison condition. But strikingly, people in the explanation condition also reported engaging in more comparison than did those in the comparison condition. Further, the success of the explanation instructions on rule discovery was partially mediated by the rate of self-reported group comparisons. Edwards et al. concluded that prompts to explain can engage people in spontaneous comparison and that this may contribute to the effectiveness of explanation in identifying a broad regularity.

Current Study

This study tests the above claims. Specifically, we test whether comparison contributes to the effect of explanation generation on children's ability to discover broad regularities. To do this, we adapted a study paradigm by Walker, Bonawitz, and Lombrozo (2017). They showed that explaining can lead children to focus on broad causal patterns. We first describe Walker et al.'s study, and then discuss a possible role for comparison.

Walker et al. tested the effect of explaining on children's causal reasoning by directly contrasting broad patterns versus specific details. They showed 4-, 5- and 6-year-old children that some gardens grew sick carrots, an outcome that could be attributed to either a single cause or two independent causes. Children saw four training gardens, two of which had red soil and two had brown soil (Figure 1 left). Each garden also contained a unique salient feature, such as a broken sprinkler or rocks. Critically, children were showed that the two red soil gardens grew sick carrots. This was consistent with two hypotheses: a broad, common cause (i.e., both sick gardens had red soils) or a context-bound hypothesis that posits two separate causes (one had a broken sprinkler, so it lacked water, and the other had a shady tree, so it lacked sunlight). Half the children were asked to explain why the two carrots were sick while the other half were simply asked to describe what they saw. The key question was whether explaining would lead children to prefer the broad (soil-based) hypothesis over the context-bound hypothesis of independent causes.

To test children's preferred explanation, children were shown four test gardens that reversed the combinations of soil types and specific objects (Figure 1 right). Children were asked to predict whether each garden grew healthy or sick carrots. If children endorsed the broad hypothesis, they should predict that the two red soil gardens (now containing the doghouse and rocks) would grow sick carrots, and the two brown soil gardens (now containing the shady tree and broken sprinkler) would grow healthy carrots. Their predictions would be the opposite if they endorsed the context-bound hypothesis.

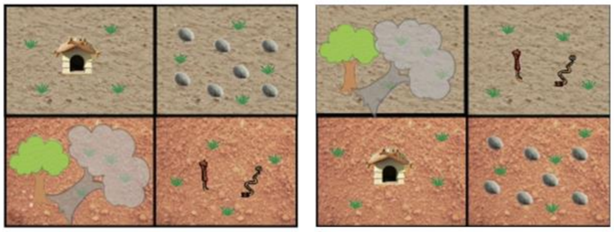

Figure 1: Training (left) and test (right) gardens used in Walker et al. and in the current experiment. Both training gardens that grow healthy carrots have brown soil (top row) and contain a doghouse and rocks; both training gardens that grow sick carrots have red soil (bottom row) and contain a shady tree and a broken sprinkler. For the test gardens, the combinations of specific objects and soil types are reversed.

The results showed an interesting developmental trend. Regardless of condition, 4-year-olds did not consistently endorse either the broad or the context-bound hypotheses, while 6-year-olds endorsed the broad hypothesis regardless of condition. However, the 5-year-olds behaved differently in the two conditions. In the Describe condition they were equally likely to choose the broad or context-bound hypotheses; but in the Explain condition, they showed a clear preference for the broad hypothesis. As the authors suggested, this developmental shift could have resulted from gains in causal knowledge. The 4-year-olds might lack sufficient domain knowledge of plant growth, while the 6-year-olds knew enough to favor the soil- type hypothesis even when not being prompted to explain. Critically, for the 5-year-olds, the specific causes—lack of water and lack of sunlight—were often highly salient at first, but explaining allowed them to overcome it and consider the broad soil type alternative more thoroughly.

These findings convincingly underscore the value of explanation generation in prompting children to arrive at broad causal patterns. But the question we raise is, to what extent did the learning benefits of explanation stem from the availability of relevant comparisons? For example, the four training gardens were displayed together and remained present throughout the study. There is considerable evidence that children are more likely to compare things when they are simultaneously present than when they occur in sequence (Alfieri et al., 2013; Begolli & Richland, 2016; Christie & Gentner, 2010; Hoyos & Gentner, 2017). Thus, seeing the four gardens together could have allowed children to compare them, facilitating children's discovery of the common soil type.

In Experiment 1a, we tested this possibility by repeating Walker et al.'s (2017) study with slight alterations designed to make comparison more difficult. We used the same materials and general procedure as did Walker et al. and the same age group (5- and 6-year-old children). One condition (Explanation+Comparison) was a close replication of Walker et al.'s Explain condition, with a few specific changes as noted below. The other condition (Explanation-Only) was matched to the Explanation+Comparison condition except for one critical difference: we minimized children's opportunity to compare. Specifically, during training, gardens were shown one at a time (unlike Walker et al., who showed all gardens simultaneously). Children were told which gardens had healthy carrots and which had sick carrots, and all were asked to explain why some carrots were sick. We added a memory check to rule out concerns about encoding errors or memory loss. The critical opportunity for comparison was manipulated during the memory check. Children were shown the gardens one by one and asked to remember whether the garden had sick carrots or healthy carrots. Critically, for the Explanation+Comparison group, each garden remained in view after the memory question and stayed visible for the rest of the study (as in Walker et al.' study). For the Explanation-Only group, the gardens were removed from sight after each question. Therefore, only the Explanation+Comparison group had access to readily available comparisons. All children then completed the Prediction task as in Walker et al.'s study. We also added a final explanation task, in which all children explained why they made their predictions.

Our main prediction is that explainers who have access to readily available comparisons should be more likely to identify the broad pattern of common soil type—as reflected in their predictions and final explanations—than those for whom comparisons are made difficult.

Experiment 1a

Methods

Participants. Twenty-six 5- and 6-year-old children were recruited for each of the two conditions—Explanation+Comparison [Expln+Comp] and Explanation-Only [Expln-Only] (*M* = 5;11 years, *Range* = 5;00 to 6;11 years; 20 females). Families were recruited through a database from a large city and compensated for participation. One participant was excluded due to memory failure (see below).

Procedure

After obtaining parental consent and the child's verbal assent, the experimenter brought the child into a quiet room. The experiment consisted of three phases—Training, Memory, and Test. The Training phase was identical between conditions. The critical manipulation of comparison opportunity occurred at the Memory and Test phases. The study took about 10 minutes.

Training. The experimenter first showed the child the picture of Mr. Farmer. They were told that he grows carrots, but that in some of his gardens, the carrots are sick. Children were invited to "…help Mr. Farmer figure out what makes the carrots healthy or sick." All children were then introduced to the four training gardens sequentially. For each, they were told, "In this garden, there is an X, and the soil is Y." (The X is "a doghouse," "rocks," "a broken sprinkler," or "a huge tree and its shadow," and the Y is "brown" or "red," respectively). The experimenter explicitly pointed to the objects and the soil while labeling these features. Next, the experimenter said, "Let's pick a carrot to see if the carrots in this garden are healthy or sick. Which one shall we pick?" After the child made a choice, the experimenter placed a healthy/ sick carrot picture underneath the garden and said, "The carrots in this garden are healthy" for each of the two brown soil gardens or "The carrots in this garden are sick" for each of the two red soil gardens. The experimenter then removed the garden picture before laying down the next one, so that the child could only see one garden at a time. The order of the gardens was fixed and alternated between healthy and sick gardens, so as to make the comparison less likely across gardens of the same soil type.

At the last garden, the child was asked for an *initial explanation* before the picture was taken away, "Mr. Farmer really wants to know what makes carrots sick. Why do you think some carrots are sick?" At this point, both hypotheses were compatible with the gardens—one based on the individual features (the context-bound hypothesis) and the other based on the common soil type (the broad hypothesis).

To summarize, we contrasted two conditions. Our Expln+Comp condition was a close replication of Walker et al.'s Explain condition. Our Expln-Only condition altered Walker et al.'s procedure in two ways designed to minimize children's tendency to compare: (1) we showed gardens sequentially, whereas Walker et al. showed them simultaneously; and (2) we alternated between healthy and sick gardens, whereas Walker et al. introduced the two healthy gardens together, followed by the two sick ones[1].

Memory. All children were again shown the four training gardens, in the same order as before. For each, children were asked, "Do you remember this garden? Does it grow healthy carrots or sick carrots?" Wrong answers were corrected. The exclusion criterion was a priori set to be more than one error. Overall, the children's memory was good. In the Expln+Comp condition, four participants each made a single error; in the Expln-Only condition, one made an error, and another made three (and was therefore excluded)[2].

The two conditions differed in one specific way. In the Expln+Comp condition, each garden was moved to one side of the table after the memory question and remained in view. In the Expln-Only condition, each garden was again taken away before laying down the next one. Therefore, by the end of the Memory phase, the Expln+Comp group could view all the gardens simultaneously, and the gardens stayed visible during the subsequent tasks. (This is comparable to Walker et al.'s procedure in the Explain condition, in which children went directly from training to test, with the gardens remaining in view).

Prediction test. The four test gardens reversed the association between soil type and concrete details. In the Prediction Test, the experimenter randomly showed the four test gardens one at a time. For each one, he asked, "This is one of Mr. Farmer's carrot gardens. If I pick a carrot from this garden, do you think it will be healthy or sick?" The test garden was taken away after each response[3]. This procedure was the same for both conditions; however, the only difference was that the Expln+Comp condition had access to the training gardens on the side.

Last, the experimenter showed each child the test gardens that the child had predicted to grow sick carrots (one at a time) and asked, "Why do you think they grow sick carrots?" If all test gardens were predicted to be healthy, the experimenter asked, "Why do you think they grow healthy carrots?" These responses constituted the child's *final explanation.*

Scoring & Coding

Prediction test. For each test garden, a child was given one point if the response was in accord with the broad hypothesis (i.e., that the two red soil gardens would produce sick carrots, and the two brown soil gardens would produce healthy ones) and zero otherwise. The max total score was 4.

Initial and final explanations. We coded these explanations according to their content. We considered three types of causes for what made carrots sick: "Soil type" if children invoked soil color; "Individual Feature" if they invoked lack of water or sunlight; and "Other" for nonexplanations and irrelevant reasons. One explanation could score multiple causes. The first author coded all the verbal responses, and two research assistants, who were not told the hypotheses, each coded half of the responses. The interrater agreement was 87%.

For the analysis, we focused on two measures: the relative frequency of mentioning each cause ("Soil type", "Individual Feature", and "Other") and the frequency of mentioning soil type as the *sole* cause. The former reveals which hypothesis children preferred, and the latter reveals the extent to which children focused on the broad hypothesis of soil type.

Results

Prediction test. (Figure 2) A t-test revealed a significant effect of condition, $t = 5.94$, $p < .001$, $d = 1.67$. Children in

[1] One other alternation is that we used pictures of healthy carrots as well as sick carrots (unlike Walker et al., who only showed pictures of sick carrots). This was done to allow feedback when prompting children to check the brown soil gardens.

[2] For the Comp-Only condition (in Experiment 1b), three children each made a single error. So no one was excluded.

[3] We again did this to make comparison difficult. This procedure was different from Walker et al.'s, which showed all four test gardens together.

the Expln+Comp condition were more likely than those in the Expln-Only condition to choose according to the broad hypothesis—that is, to predict that the test gardens with red soil were sick and those with brown soil were healthy (M_{E+C} = 3.41, SD_{E+C} = 1.17; $M_{E\text{-}Only}$ = 1.16, $SD_{E\text{-}Only}$ = 1.52). Moreover, the Expln-Comp group produced the broad pattern of choices at above-chance rates, $t = 6.19$, $p < .001$, $d = 1.21$, while the Expln-Only group did so at below-chance rates, $t = -2.77$, $p = .011$, $d = -0.44$.

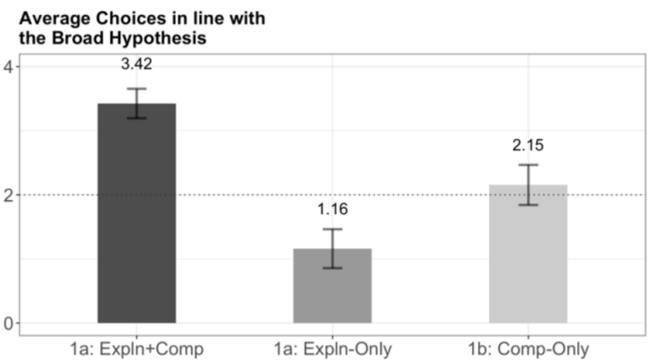

Figure 2. Results of E1a & E1b: Prediction test performance by condition. Error bars represent standard errors.

Explanation task. We looked first at the relative frequency of mentioning each cause in children's explanations. In the initial explanation (Figure 3, left), the frequency distribution did not significantly differ between conditions, Fisher's exact test, $p = .064$. This was expected since the training procedure to that point was identical for the two groups. In contrast, as predicted, in the final explanation (Figure 3, right), there was a significant condition difference, Fisher's exact test, $p < .001$. Only the Expln+Comp group predominantly explained by the soil type.

We also calculated the rate of mentioning soil type as the *sole* cause. For the initial explanation, a Chi-squared test revealed no difference between the Expln+Comp group (9 out of 26) and the Expln-Only group (3 out of 25) in their tendency to do so, $\chi^2 = 2.47$, $p = .12$. For the final explanation, the Expln+Comp group (18 out of 26) was significantly more likely than the Expln-Only group (4 out of 25) to name the soil type as the sole cause of sick carrots, $\chi^2 = 12.6$, $p < .001$. Together, these patterns suggested that, while no particular cause was favored at first, having comparisons readily available led explainers to shift focus to the common soil patterns. Without such opportunity, the Expln-Only group remained variable in their explanations.

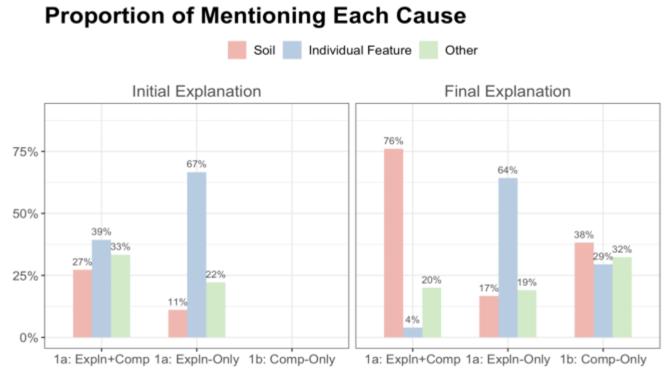

Figure 3. Results of E1a & E1b: Explanation task performance by condition.

Experiment 1b

The results of Experiment 1a replicate prior findings concerning the benefits of explanation. Children who explained (when comparison was possible) made predictions according to the broad hypothesis (soil type) and were more likely to endorse common soil type in their final verbal explanations. The results also show the critical role of comparison in identifying broad patterns. Children who explained but did not receive the opportunity to compare failed to endorse the broad hypothesis in their predictions and explanations. That is, having an explanatory goal led to the broad hypothesis only when children could readily compare the items. These results provide support for the claim that comparison is integral to the explanatory process.

Given these findings, one extreme possibility is that *all* the benefits of explanation are due to comparison. That is, as long as the comparison opportunity is present, children do not need explanation to endorse the broad pattern. Alternatively, we have proposed that the goal of explaining a phenomenon actively engages a search for informative comparisons. Experiment 1b examines whether comparison by itself is enough to drive children's preference for broad regularities. A new group, the Comparison-Only condition, completed the study in the same way as the Expln+Comp condition in Experiment 1a, except for one critical difference: this group did not explain during training why some carrots were sick.

Methods

Participants. Twenty-six 5- and 6-year-old children participated in the Comparison-Only (Comp-Only) condition (*M* = 6;00 years, *Range* = 5;01 to 7;00 years; 13 females). Children were recruited using the same methods as in Experiment 1a. All children passed the memory task.

Procedure

The Comp-Only condition received the identical procedure as did the Expln+Comp condition from E1a, except in one important respect: they were not asked for the initial explanation during training. Children saw each of the training gardens in the same sequence and learned that the two brown soil gardens (with a doghouse and rocks) grew healthy carrots while the two red soil gardens (with a broken sprinkler and a shady tree) grew sick carrots. However, after the last garden, the Comp-Only group simply heard, "Let's see how well you remember the gardens." and moved on to the memory task. The rest of the procedure was identical to that of the Expln+Comp condition in E1a. In the memory task, the child was asked to remember the state of the carrots for each training garden; each garden was then pushed to the side and remained in view. In the Prediction task, with the training gardens on the side, children were asked whether each of the four test gardens would grow healthy or sick carrots. Last, each child was shown the test garden(s) that they had predicted would grow sick carrots and asked, "Why do you think it grows sick carrots?" This constituted their final (and only) explanation.

Results

Prediction task. Figure 2 shows the performance of the Comp-Only condition ($M_{C\text{-}Only}$ = 2.15, $SD_{C\text{-}Only}$ = 1.59). T-tests revealed that this group, which did not engage in explanation, was at chance in predicting that the test gardens with red soil were sick. They were significantly less likely to follow the broad hypothesis of soil type than were the Expln+Comp group from E1a, t = -3.27, p = .002, d = -0.91. However, interestingly, this group was more likely to follow the broad hypothesis than were the Expln-Only group, t = 2.28, p = .027, d = 0.64.

Explanation task. Children in the Comp-Only condition gave only the final explanation (Figure 3). Their frequency of mentioning each cause significantly differed from those of the Expln+Comp group, Fisher's exact test, p = .007.

Consistent with this pattern, only 10 out of 26 children in the Comp-Only group reported soil type as the *sole* cause for what made carrots sick, as compared to 18 in the Expln+Comp group. However, a Chi-squared test failed to reveal a significant difference, χ^2 = 3.79, p = .052.

Discussion

The results of Experiment 1b showed that without the prompt to explain, children did not focus on the broad cause of soil type in their predictions and final explanations, despite having readily available comparisons. This paralleled the patterns of the Explanation-Only group in Experiment 1a. The current results also paralleled the findings of Walker et al.'s control condition, in which simply describing the gardens did not lead 5-year-old children to endorse the broad hypothesis (though their 6-year-olds succeeded)[4].

These results join with prior findings (Edwards et al., 2019) in supporting our two claims (1) that generating explanations (often) recruits comparison; and (2) that the comparison process facilitates the construction of broad explanations.

More generally, we argue that explanation and comparison often jointly benefit everyday learning. Engaging in explanation-seeking can instill curiosity and motivate children to try to understand the phenomena. To achieve this, explainers often need to seek available comparisons in the environment (or in their own prior knowledge). Through the structural alignment process of comparison, learners come to notice common relational patterns across the cases to be explained. These commonalities provide the material for satisfying explanations.

We suggest that both explanation and comparison are critical in coming to understand everyday phenomena. When comparison is unavailable, children who are trying to explain something will likely resort to salient inherent features of individual objects (e.g., a broken sprinkler; Cimpian, 2015). Similarly, without the goal of explaining, children may not utilize the readily available comparison opportunity, or they may not prioritize the common patterns in their reasoning.

We have focused here on the role of comparison in revealing common relational structures, but the comparison process can also benefit explanation by rendering important *differences* more salient, as argued by Chin-Parker & Bradner (2010, 2017). Evidence comes from a study by Hoyos and Gentner (2017). They asked whether explanation and comparison can benefit learning of differences. They showed six-year-old children a pair of model buildings—one with a diagonal brace (which was stable) and one with a horizontal crosspiece (which was unstable). Children were asked to explain why the stable building was stronger. For half the children, the buildings looked similar and were easy to align. For the other half, the two buildings were difficult to align. The results showed that ease of alignment was a strong predictor of answering correctly (that the building with the diagonal brace was stronger). Indeed, those who saw the hard-to-align pair mostly explained by overall shape and surface differences. Hoyos and Gentner suggested that although children might have initially focused on the surface properties of the two buildings, when given two buildings that were highly similar (and easily aligned), children readily engaged in structural alignment. This led them to notice the alignable difference between the diagonal brace and the horizontal piece.

Conclusion

Explanation-generation is a productive learning process in both children and adults. Our results suggest that its power stems in part from invoking comparison processes. More broadly, we suggest that explanation and comparison are mutually scaffolding. Explanation and comparison may work in concert to promote learning.

[4] We did not find such an age difference in our study. Separate analyses of 5- and 6-year-olds in the Comp-Only condition revealed no evidence that either group endorsed the broad hypothesis.

References

Alfieri, L., Nokes-Malach, T. J., & Schunn, C. D. (2013). Learning through case comparisons: A meta-analytic review. *Educational Psychologist*, *48*(2), 87-113.

Begolli, K. N., & Richland, L. E. (2016). Teaching mathematics by comparison: Analog visibility as a double-edged sword. Journal of Educational Psychology, 108(2), 194.

Begolli, K. N., Richland, L. E., Jaeggi, S. M., Lyons, E. M., Klostermann, E. C., & Matlen, B. J. (2018). Executive function in learning mathematics by comparison: Incorporating everyday classrooms into the science of learning. *Thinking & Reasoning*, *24*(2), 280-313.

Bisra, K., Liu, Q., Nesbit, J. C., Salimi, F., & Winne, P. H. (2018). Inducing self-explanation: A meta-analysis. *Educational Psychology Review*, *30*(3), 703-725.

Busch, J. T., Willard, A. K., & Legare, C. H. (2018). Explanation scaffolds causal learning and problem solving in childhood. Active learning from infancy to childhood: Social motivation, cognition, and linguistic mechanisms, 113-127.

Callanan, M. A., & Oakes, L. M. (1992). Preschoolers' questions and parents' explanations: Causal thinking in everyday activity. *Cognitive development*, *7*(2), 213-233.

Chen, Z. (1999). Schema induction in children's analogical problem solving. Journal of Educational Psychology, 91(4), 703.

Chi, M. T. (2013). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In *Advances in instructional Psychology, Volume 5* (pp. 161-238). Routledge.

Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive science*, *13*(2), 145-182.

Chi, M. T., De Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive science*, *18*(3), 439-477.

Chin-Parker, S., & Bradner, A. (2010). Background shifts affect explanatory style: How a pragmatic theory of explanation accounts for background effects in the generation of explanations. *Cognitive processing*, *11*(3), 227-249.

Chin-Parker, S., & Bradner, A. (2017). A contrastive account of explanation generation. *Psychonomic Bulletin & Review*, *24*(5), 1387-1397.

Christie, S., & Gentner, D. (2010). Where hypotheses come from: Learning new relations by structural alignment. *Journal of Cognition and Development*, *11*(3), 356-373.

Cimpian, A. (2015). The inherence heuristic: Generating everyday explanations. *Emerging trends in the social and behavioral sciences: An interdisciplinary, searchable, and linkable resource*, 1-15.

A., & Bangert, A. S. (2004). On the spontaneous discovery of a mathematical relation during problem solving. Cognitive Science, 28(3), 433-449.

Edwards, B. J., Williams, J. J., Gentner, D., & Lombrozo, T. (2019). Explanation recruits comparison in a category-learning task. *Cognition*, *185*, 21-38.

Forbus, K. D., Ferguson, R. W., Lovett, A., & Gentner, D. (2017). Extending SME to handle large-scale cognitive modeling. *Cognitive Science*, *41*(5), 1152-1201.

Gentner, D. (2003). Why we're so smart. *Language in mind: Advances in the study of language and thought*, *195235*.

Gentner, D. (2010). Bootstrapping the mind: Analogical processes and symbol systems. *Cognitive Science*, *34*(5), 752-775.

Gentner, D., & Hoyos, C. (2017). Analogy and abstraction. *Topics in cognitive science*, *9*(3), 672-693.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive psychology*, *15*(1), 1-38.

Hilton, D. J., & Slugoski, B. R. (1986). Knowledge-based causal attribution: The abnormal conditions focus model. *Psychological review*, *93*(1), 75.

Hoyos, C., & Gentner, D. (2017). Generating explanations via analogical comparison. *Psychonomic Bulletin & Review*, *24*(5), 1364-1374.

Keil, F. C. (2006). Explanation and understanding. Annu. Rev. Psychol., 57, 227-254.

Landy, D., & Hummel, J. (2010). Explanatory reasoning for inductive confidence. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 32, No. 32).

Legare, C. H., & Lombrozo, T. (2014). Selective effects of explanation on learning during early childhood. Journal of experimental child psychology, 126, 198-212.

Legare, C. H., Sobel, D. M., & Callanan, M. (2017). Causal learning is collaborative: Examining explanation and exploration in social contexts. Psychonomic bulletin & review, 24, 1548-1554.

Lombrozo, T. (2006). The structure and function of explanations. *Trends in cognitive sciences*, *10*(10), 464-470.

Lombrozo, T. (2016). Explanatory preferences shape learning and inference. *Trends in Cognitive Sciences*, *20*(10), 748-759.

Lombrozo, T., & Carey, S. (2006). Functional explanation and the function of explanation. *Cognition*, *99*(2), 167-204.

Loewenstein, J., Thompson, L., & Gentner, D. (2003). Analogical learning in negotiation teams: Comparing cases promotes learning and transfer. *Academy of Management Learning & Education*, *2*(2), 119-127.

Markman, A. B., & Gentner, D. (1993). Structural alignment during similarity comparisons. *Cognitive psychology*, *25*(4), 431-467.

Muldner, K., Burleson, W., & Chi, M. T. (2014). Learning from self-explaining emergent phenomena. Boulder, CO: International Society of the Learning Sciences.

Nokes-Malach, T. J., VanLehn, K., Belenky, D. M., Lichtenstein, M., & Cox, G. (2013). Coordinating principles and examples through analogy and self-explanation. European Journal of Psychology of Education, 28, 1237-1263.

Rittle-Johnson, B. (2006). Promoting transfer: Effects of self-explanation and direct instruction. *Child development*, *77*(1), 1-15.

Rittle-Johnson, B., Loehr, A. M., & Durkin, K. (2017). Promoting self-explanation to improve mathematics learning: A meta-analysis and instructional design principles. ZDM, 49, 599-611.

Sidney, P. G., Hattikudur, S., & Alibali, M. W. (2015). How do contrasting cases and self-explanation promote learning? Evidence from fraction division. *Learning and Instruction*, *40*, 29-38.

Thompson, C. A., & Opfer, J. E. (2010). How 15 hundred is like 15 cherries: Effect of progressive alignment on representational changes in numerical cognition. *Child Development*, *81*(6), 1768-1786.

Walker, C. M., & Lombrozo, T. (2017). Explaining the moral of the story. *Cognition*, *167*, 266-281.

Walker, C. M., Lombrozo, T., Legare, C. H., & Gopnik, A. (2014). Explaining prompts children to privilege inductively rich properties. *Cognition*, *133*(2), 343-357.

Walker, C. M., Bonawitz, E., & Lombrozo, T. (2017). Effects of explaining on children's preference for simpler hypotheses. *Psychonomic bulletin & review*, *24*(5), 1538-1547.

Walker, C. M., & Lombrozo, T. (2017). Explaining the moral of the story. Cognition, 167, 266-281.

Williams, J. J., & Lombrozo, T. (2010). The role of explanation in discovery and generalization: Evidence from category learning. *Cognitive science*, *34*(5), 776-806.