Analogy Use in Parental Explanation

Yang Gao[1], Kexin Que[2], Zijing Tan[2], Yi Zhang[2], Stella Christie[1,2]
gaoy20@mails.tsinghua.edu.cn, kexinque@gmail.com, catherine.tan823@gmail.com, zhangyipku@163.com, christie@tsinghua.edu.cn
[1] Department of Psychology, Tsinghua University, Beijing, China, 100084
[2]Tsinghua Laboratory of Brain and Intelligence, Tsinghua University, Beijing, China, 100084

Abstract

How and why are analogies spontaneously generated? Despite the prominence of analogy in learning and reasoning, there is little research on whether and how analogy is spontaneously generated in everyday settings. Here we fill this gap by gathering parents' answers to children's real questions, and examining analogy use in parental explanations. Study 1 found that parents used analogy spontaneously in their explanations, despite no prompt nor mention of analogy in the instruction. Study 2 found that these analogical explanations were rated highly by parents, schoolteachers, and university students alike. In Study 3, six-year-olds also rated good analogical explanations highly, but unlike their parents, did not rate them higher than causal, non-analogical explanations. We discuss what makes an analogy a good explanation, and how theories from both explanation and analogy research explain one's motivation for spontaneously generating analogies.

Keywords: analogy; explanation; causal reasoning; learning

Introduction

How is an analogy generated? Despite a rich tradition of research in analogical reasoning (e.g., Gentner & Hoyos, 2017; Hofstadter, 2001), the question of what makes someone produce an analogy and when they are likely to do so remains elusive. This gap of knowledge is particularly interesting given the extensive evidence from both developmental literature (e.g., Christie, Gao, & Ma, 2020) and work with adults (see recent review by Gentner & Hoyos, 2017) that analogical comparison is an effective, readily available learning tool, which aids knowledge acquisition and problem solving. For example, in a classic study by Gick and Holyoak (1980), adults who were given hints to use analogical comparison were better able to solve the problems. Likewise, 4-year-olds who heard a comparison of analogous thoughts performed better in a later false-belief task than did those who had not experienced the analogy (Hoyos et al., 2020). Since analogy is useful and helpful, why isn't it used extensively by everyone?

One obvious reason is that generating analogy—mapping relations from a familiar (base) to an unfamiliar (target) event—is not easy. Laboratory studies often found that adults fail to retrieve analogical matches because the base analogs do not seem related or similar to the target (e.g., Gentner, Rattermann & Forbus, 1993; Keane, 1987; Trench & Minervino, 2015). There is an over-reliance on surface level similarities; people generate analogies only when things look similar. However, experts who have the habit of encoding events (or facts) not only as a set of features but also as a relational structure are less likely to be constrained by surface similarities (Chi et al., 1981; Medin et al., 1983). As a result, they are better able to see similarities between distant events, and thereby more likely to generate spontaneous analogies compared to novices (Goldwater et al., 2021).

Who are the "experts" that often generate and/or use analogy in the real world? In general, analogy research has looked at two groups of presumed experts: scientists and teachers. A plethora of studies have documented scientists' use of analogies to aid scientific discoveries (Dunbar, 2001; Dunbar & Blanchette, 2001; Gentner, 2002; Gentner et al., 1997). Konrad Lorenz even titled his Nobel Prize acceptance speech "Analogy as a source of knowledge" (Lorenz, 1974). The other well-studied group is teachers. Across mathematics, science, geology, and history classrooms, teachers make extensive use of analogy, which has been shown to correlate with improved performance among students (Begolli & Richland, 2016; Dagher, 1995; Richland & Simms, 2015).

But while studies of analogy generation and usage among scientists and teachers have delivered important findings, they do not fully address the issue of *spontaneous* analogy generation. Scientists are reputed to use analogy within their domain of expertise, with the overt goal of advancing their work. Not surprisingly, like Lorenz, scientists are often aware of the role of analogy in their thinking process (Hofstadter & Sander, 2013). Among teachers, usage of analogy in the classrooms likely comes from teaching preparation rather than from spontaneous, on-the-spot thinking. Furthermore, teachers often use preexisting, readily available analogies (for example, the water flow analogy for electrical circuits) rather than generating fresh ones. This is not to undermine explicit intent or preparation; as reviewed above, there is ample evidence that students (and scientists) benefit from analogy use (Begolli & Richland, 2016). That said, we must look elsewhere to get a picture of how analogies are spontaneously generated in everyday reasoning.

Parents—in particular parents explaining to young children—present a good opportunity for investigating spontaneous analogy generation. Young children ask a huge number of questions (Chouinard, 2007; Corriveau & Kurkul, 2014; Greif, Nelson, Keil, & Gutierrez, 2006; Kemler Nelson & O'Neil, 2005; Kurkul & Corriveau, 2018; Mills, Legare, Bills, & Mejias, 2010) and most often direct them at their best "experts"—parents. Since children's questions vary widely, spanning the gamut from science (Chouinard, Harris, &

Maratsos, 2007) to social norms (Callanan & Oakes, 1992), parents' explanations—in contrast to scientists—are not limited to a domain of expertise. In fact, parents have to be ready to be experts in everything. Unlike teachers' groomed classroom presentations, parents must give explanations on the go, responding to children's here-and-now inquiries. Overall, while there is a constant element of familiarity (parents are answering their own children's questions), parents' explanations are generally spontaneous and cover a wide range of topics. Do parents use analogy in their explanations to children's questions? Why or why not? Investigating this gives an important window to how analogies are generated spontaneously.

To our knowledge, there is no study that looks at analogy generation within the context of parental explanation to young children. As such, in the current research we first needed to establish the frequency of parents spontaneously using analogy in their explanations (Study 1). Following this, in Study 2 we asked whether parents' explanations that contain analogies are perceived as good, relative to non-analogical explanations. In Study 3 we asked whether this perception is shared equally between parents and young children.

Study 1: Do parents use analogy spontaneously?

Design, Participants, and Procedure

In order to understand real, spontaneously-generated analogies in parental explanation, in Study 1 we first collected children's real-life questions (Phase 1) and then asked parents to give explanations to these questions (Phase 2).

In Phase 1 Child-Question, we sent out an internet article inviting families of 2- to 9-year-old children to submit real questions from children. In total, we received 133 children's real-life questions ranging from philosophical questions such as "Where do people go after death?" to daily life questions such as "Why do I have to do my homework?" Most questions we received were about daily life (49%), followed by science-related (31%), social (10%), and philosophical (10%). We were interested in whether some types of children's questions were more likely to generate analogical explanations, hence for Phase 2, we selected 28 questions: daily life (14), science (6), philosophical (5), and social (3); see Table 1 for sample questions. We deliberately chose more daily life questions as this category is potentially the most interesting test bed for spontaneous analogy generations. In addition, previous research on adults-to-children explanations were focused more on science related questions (Leech et al., 2020; Lombrozo & Carey, 2006; Willard et al., 2019).

In Phase 2 Parent-Explanation, we invited parents to answer these 28 questions. To maximize spontaneity and ecological validity, the questions were distributed singly–we put one question per day on an internet poll-like posting. In total, 257 parents gave 257 explanations (each parent participant only gave one explanation) to the 28 questions. Five experimenters (trained analogy researchers) coded whether the explanations contained analogy or not. Parents and children are from mainland China, and the study was conducted in Mandarin Chinese.

Table 1. Examples of children's questions (Q) and parents' explanations (analogy and non-analogy)

Questions and explanations are translated from Mandarin Chinese, but not edited.

Q1 *Daily Life*: "Why do we have to eat?"
E1-Analogy: "Studying, working, walking, blinking, and breathing, all these activities consume energy. Eating is supplementing energy, just like cars need fuel or electricity as energy.
E1-Non Analogy: "You will grow tall if you eat (Non-analogy)

Q2 *Philosophical*: "Is there someone in the sky looking at us just like how we look at ants?"
E2-Analogy: "Of course! When I look at people on the ground from an airplane or from the Guangzhou Tower, they are like ants."
E2-Non Analogy: "Maybe. What will we look like from their perspective?"

Q3 *Science*: "Why is the earth round but it seems flat?
E3-Analogy: "Just like if an ant is sitting on a basketball, it will think that the ball is flat."
E3-Non Analogy: "The Earth is so large that a small part of it is flat."

Q4 *Social*: "Why did you marry dad if you dislike him?"
E4-Analogy: "Just like how I hate rain in the summer but I like watermelons in the summer, I do not dislike a person. Rather, I dislike some of his behaviors, but like some. I do not dislike your dad. I like him so much that I do not want to separate from him. We want to spend the rest of our time together, so we got married."
E4-Non-Analogy: "I did not dislike him this much before living together."

Results and Discussions

Parents do in fact use analogy in their explanations to children's actual questions. Out of the 257 explanations we collected, 14% (36 out of 257) were explanations containing analogy. As there is no baseline of prior studies, currently we are not able to make a relative statement about this frequency. However, this data should be useful for future comparison, for example comparing different demographics or parents of different cultures.

We were also interested in knowing whether some types of questions were more likely to generate analogical explanations. Among the 28 questions, 50% (14 out of 28) generated analogical explanations. Analyzing the question type, we found that philosophical questions were the least likely to generate analogical explanations (1.85% of the explanations contained analogies), while all other three question types generated similar percentages of analogical explanation (daily life 17.86%, science, 16.42%, social, 16.67%, Figure 1).

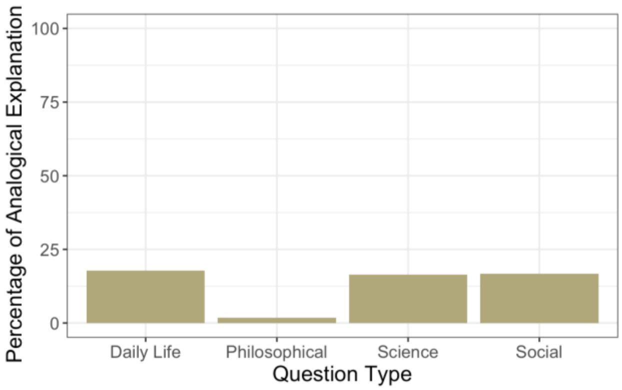

Figure 1. Study 1: Percentages of analogical explanations for each question type.

Study 2: How do analogical explanations compare to non-analogical ones?

In Study 2 we investigated people's perception of analogical explanations. While previous studies have looked at what makes an explanation a good one (e.g., Frazier, Gelman & Wellman, 2016; Lombrozo, 2007), few studies directly ask whether explanations containing analogy are judged to be good explanations. Establishing this is important in order to understand the motivation (or lack thereof) for using analogy in everyday explanations. To test this, we used a subset of the spontaneous explanations generated by real parents in Study 1 (as opposed to using explanations generated by experimenters) and asked a new group of parents to rate these explanations. We also asked college students, because they often receive explanations (e.g. from professors), and elementary school teachers, because they often give explanations, to rate the goodness of these explanations. We were interested in knowing how people rated the analogical vs. non-analogical explanations, and whether parents, college students, and teachers differed in their ratings.

Method

Participants We recruited 262 participants through university class channel (students), online advertisements (parents), and primary schools (teachers). All participants reside in mainland China, and speak Mandarin Chinese as their native language. After applying an exclusion criterion (explained below), the final sample was 201: 69 university students (freshman to junior undergraduates), 61 parents (of children ages 0-13 years, mean = 6.1 years), and 71 elementary school teachers (age range = 24-35 years).

Materials and Procedure We selected 73 explanations from Study 1 (explanations from parents to children's actual questions) containing analogical explanations (35) and non-analogical explanations (34), and 4 "catch" explanations–2 highly-rated and 2 lowly-rated explanations (as rated by 5 experimenters). The catch explanations were included as exclusion criteria, to check that participants did not just give all high or all low ratings indiscriminately.

Participants rated 73 explanations (each explanation appeared with its corresponding question) on a seven-point scale (1 = very unsatisfied, 7 = very satisfied) using an online survey. At the beginning of the survey participants were told that the questions came from children and that real parents gave these explanations.

Results

Exclusion criteria Originally we included 4 catch explanations (2 High, 2 Low) as a check of participants' engagement in the task. However, analysis of the catch explanations showed that one of the High Catch explanations yielded low ratings from the participants. As such, we only used 3 catch trials as an exclusion criterion. Participants with more than 2 standard deviations away from the mean ratings of the catch explanations were excluded from the final analysis (N_{Final}= 201).

People's ratings for analogical vs. non-analogical explanations Data were analyzed using linear mixed-effects models (lmer4 package) in R Studio (Bates et al., 2014). The satisfaction ratings were z-scored within each group (parents, students, teachers). All models included random intercepts for participant identity. Our significance threshold was a two-tailed alpha level of 0.05.

Overall, parents, teachers, and students gave higher ratings for analogical explanations than for non-analogy explanations (parents: 95% CI [-0.412,-0.310], standardized β= -0.361, SE = 0.026, $t(4148) = -13.854$, $p< .001$; students: [-0.417,-0.309], standardized β= -0.363, SE = 0.027, $t(4692) = -13.273$, $p< .001$, teachers: [-0.472,-0.376], standardized β= -0.424, SE = 0.025, $t(4828) = -17.27$, $p< .001$. No group differences were found (Figure 2).

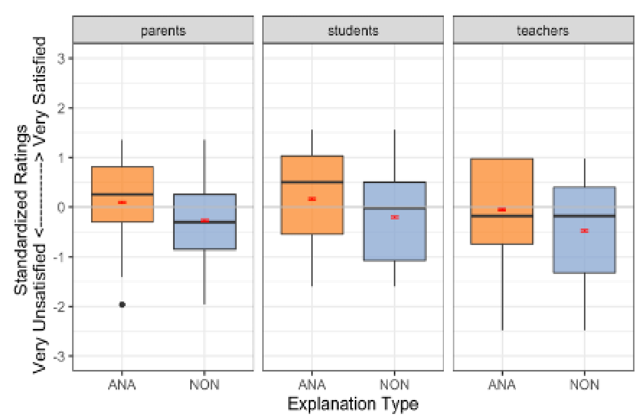

Figure 2. Study 2: Ratings (z-scored) of analogical explanations (ANA) and non-analogical explanations (NON). All groups (parents, students, teachers) gave higher ratings for analogical than for non-analogical explanations.

People's ratings for good vs. bad analogy explanations We were interested in whether people were sensitive to the quality of analogical explanations. To investigate this, 5 experimenters who are trained analogy researchers first independently rated the explanations as good analogy (score 1) vs. bad analogy (score 0). The rating from all 5 experimenters were added to give the total score (max. 5). Explanations receiving a total score of 4 or 5 were deemed as Good-Analogy explanations, while those with a total score of 1 or 0 were categorized as Bad-Analogy. Using such criterion, we found people's ratings were aligned with experimenters' ratings. That is, participants were more satisfied with explanations containing good analogy than explanations containing bad analogy (Parents, 95% CI [0.253, 0.394], standardized β=0.324, SE = 0.036, $t(2074)=9.046$, $p<.001$. Students, [0.500,0.645], standardized β= 0.572, SE=0.037, $t(2346)=15.476$, $p< .001$. Teachers, [0.202, 0.332], standardized β=0.267, SE=0.033, $t(2414)=8.086$, $p< .001$; Figure 3).

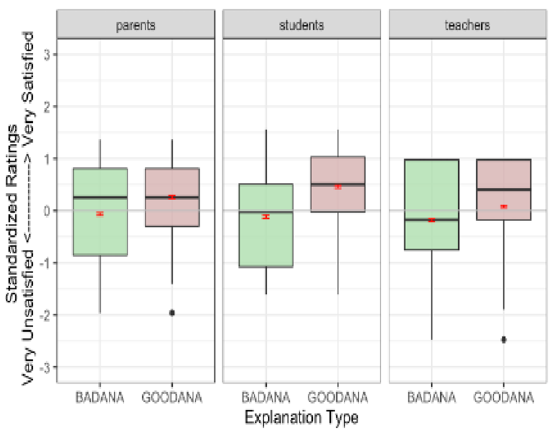

Figure 3. Study 2: Parents, students, and teachers gave higher ratings (z-score) for explanations with good-analogy (GOODANA) than for those with bad-analogy (BADANA).

The effect of length on satisfaction ratings On average, analogical explanations were longer than non-analogical ones (mean $length_{analogy}$ = 29 characters[1], mean $length_{non\text{-}analogy}$ = 20 characters). Moreover, good analogical explanations were generally longer than bad analogical explanations (mean $length_{good\ analogy}$= 54 characters, mean $length_{bad\ analogy}$= 27 characters). To see whether length predicts goodness of ratings, we added both length and explanation type as fixed factors. We found that the effect of explanation type still existed after taking length into account: participants rated explanations that contain analogy better than those without analogy [-0.236, -0.175], standardized β=-2.057e-01, SE = 1.591e-02, $t(13670)=-12.928$, $p< .001$. Likewise, good analogical explanations were rated higher than bad analogical explanations [0.214, 0.303], standardized β=2.591e-01, SE = 2.257e-02, $t(6834)=11.482$, $p< .001$.

To further control for length, we analyzed analogical and non-analogical explanations matched in length (15 explanations). Using explanation type and length as fixed factors, we again found that analogical explanations were still rated higher than non-analogical ones [-0.222, -0.095], standardized β=-0.159, SE=0.032, $t(2811)=-4.885$, $p< .001$. The effect of length was not significant [-0.010,0.072], standardized β=0.031, SE =0.018, $t(6)=1.732$, $p=.134$. Taken together, while analogical explanations are longer, length does not predict satisfaction rating of an explanation.

Study 3: Children's ratings of analogical explanations

Study 2 shows that analogical explanations are rated highly by parents, university students, and teachers alike. Because these explanations were given as responses to children's questions, it makes sense to ask whether children themselves think that analogical explanations are satisfactory answers. To do so, in Study 3 we asked a new group of parents and their children to rate analogy and non-analogy explanations. We were interested both in the group's differences (parents vs. children), as well as in the individual parent-child pair agreement.

Method

Participants Ten parent-child pairs participated. Children were 6-year-olds, (5 females, mean age = 6.3 years, range = 5-7 years); parents' mean age was 38 years (all females, range = 34-42 years).

Materials and Procedure As in Study 2, we made a selection from real children's questions and parents' explanations gathered in Study 1. While in Study 2 we aimed for a broad analysis of a large number of explanations, in Study 3 we reduced the number of explanations to accommodate child participants and to control for explanation length. This yields 4 questions with 4 types of explanations: good analogy (A1), bad analogy (A0), good non-analogy (N1), and bad non-analogy (N0). These good vs. bad categories (for both analogy- and non-analogy explanations) are created based on Study 2 participants' (parents, teachers, university students) high and low ratings respectively. To control for length, we matched the length of good analogy (mean = 43 characters) and good non-analogy (mean = 39 characters). Note that it is not possible to match the length of all 4 types as these are real explanations and naturally the bad explanations are shorter than the good ones. After selecting for matching length, we found that all good, non-analogical explanations are causal explanations.

All participants saw all 16 explanations, randomly distributed in two blocks. In the first block, each question and each type of explanation only appeared once. The second block included all the remaining 12 explanations. We also included two catch explanations (one high, one low) to check for participants' engagement.

Parents and children rated the explanations on a five-point scale (1 = very unsatisfied, a very sad face (for children), 5 = very satisfied, a very happy face (for children)). Since

[1] As explanations were in Mandarin Chinese, length was calculated using count of Chinese characters.

children in our target age group have limited reading ability, we presented them with an audio survey. Parents received the text version to ensure that children did not accidentally overhear their parents doing the survey. We instructed parents to first complete the survey without their children so children could independently do their ratings.

Table 3. Examples of 4 types of explanation used in Study 3

Child's Question: "Why do people have to eat?"
Good Analogy (A1): "Just like Dad's phone needs charging or it would not work, we gain energy from eating. If you eat timely, you can grow up and grow tall fast."
Bad Analogy (A0): "There is a little elf in your tummy that needs to eat."
Good Non-analogy (N1): "We need energy, and eating is our primary way of obtaining energy. Hydrocarbon, protein, and fat in the meals will provide us energy."
Bad Non-analogy (N0): "You will starve if you do not eat."

Results

Participants who rated the low catch as higher than 3 or who rated the high catch as lower than 3 were excluded from the final analysis (4 child-parent pairs). Given the small final sample, the analysis below is preliminary. Further data collection is ongoing at the time of writing.

We first analyzed whether as a group, children differed from parents in their ratings of explanations. They did, but only for the good analogy explanations, where parents gave higher ratings than children (95% CI [-0.526,0.528], standardized β=0.001, SE= 0.2635, *t*(48) =0.004, *p*=0.996). For the other three types of explanations, children and parents did not differ in their ratings.

Next, we analyzed ratings for good vs. bad explanations. Overall, parents and children gave higher ratings for good explanations (with or without analogy) than for bad explanations (with or without analogy) (Good (A1+N1) vs. Bad (A0+N0), [0.5495,1.067], standardized β=0.8081, SE=0.1312, *t*(186)=6.157, *p*<0.001), see Figure 4. We then analyzed the impact of analogy on children's and parents' perception of explanations. Analogy did not make a bad explanation better—bad analogy were rated the same as bad non-analogy explanations (Children: A0 vs. N0, [-0.3581,0.7826], standardized β=0.2123, SE=0.2852, *t*(48)=0.744, *p*=0.460. Parents: A0 vs. N0, [-0.7369,0.2896], standardized β=-0.2236, SE=0.2559, *t*(42)=-0.874, *p*=0.387.) However, using good analogy in an explanation did bring extra satisfaction for parents (Parents-Good Analogy vs. Good Non-Analogy: [-0.969, -0.148], standardized β=-0.559, SE=0.204, *t*(42)=-2.729, *p*<0.01). This effect was not observed in children (Good Analogy vs. Good Non-Analogy: [-0.2135,0.8200], standardized *β*=0.303, SE=0.257, *t*(42)=1.177, *p*=0.246). That is, for children, good analogical explanations are simply good, but not better than the non-analogical, causal explanations.

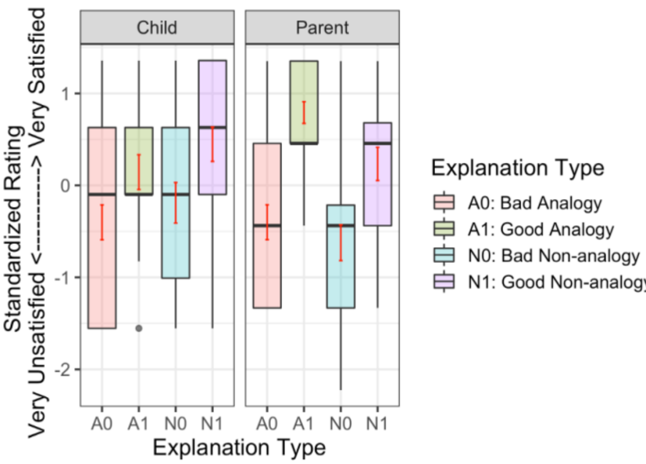

Figure 4. Study 3: Parents' and children's ratings of 4 types of explanations: Bad Analogy (A0), Good Analogy (A1), Bad non-analogy (N0), Good Non-analogy (N1). In general, children and parents rated good explanations (with or without analogy) higher than bad explanations (with or without analogy).

Child-parent correlation in satisfaction ratings Aside from group similarity between parents and children, we are also interested in the individual parent-child pair. That is, does parent X agree (or disagree) more with their own child? This is an interesting question as some may assume that children's perception of what counts as good or bad explanations should conform more to their parents' perception. To investigate this, we calculated the Pearson correlation coefficient within each child-parent pair (child and their own parent) and across different pairs (child and other parents) based on the ratings of all explanation types (A0, A1, N0, N1). We found that for each child-parent pair, the within child-parent pair correlation did not differ from the across-pair correlation (min [-1.165,0.053], standardized β=-0.555, SE=0.297, *t*(22)=-1.868, *p*=0.075). Thus, no particular correlation in explanation satisfaction rating is seen between children and their parents.

General Discussion

Despite the prominence of analogy as a learning and reasoning tool, we know surprisingly little about spontaneous generation of analogies in everyday reasoning. To bridge this knowledge gap, we explored a commonly occurring situation—parents explaining to children—and asked whether it begets spontaneous analogy generation. Faced with real questions from children, we found that parents did spontaneously use analogy in their explanations 14% of the time in our study. That parents should use analogy at all in their explanations is noteworthy for several reasons: (1) Analogy was never mentioned in our experimental setup. Each occurrence of analogy appeared entirely without prompting, on a purely spontaneous basis. (2) Prior research on parental explanations to children reports that the quality of parental explanations is not high (Crowley et al., 2001; Shtulman & Checa, 2012; Valle, 2009). (3) There was no quality control on the questions asked by children. This is in contrast with groups studied in prior research—teachers and scientists—who employed analogies for questions of definite intellectual caliber. For the first time, we report that people use analogy in a self-motivated, relaxed context, and not in a professional setting when driven by externally set goals.

As it is rather remarkable that parents use analogy when explaining things to young children, it behooves us to ask why: what is the motivation for employing analogy? To begin addressing this question, in Study 2 we asked parents (different from the ones who gave the explanations in Study 1), university students, and elementary school teachers to rate a set of explanations, which included both analogical and non-analogical ones. The results show that all groups gave higher ratings to analogical explanations. Moreover, people seem sensitive to the quality of the analogy, with good-analogy explanations rated higher than bad-analogy explanations. Again, the instruction given to participants was simply to rate their satisfaction of an explanation. Analogy was never mentioned, as a criterion or otherwise, nor was it suggested by any prior conditioning. The results suggest a simple yet powerful motivation for using analogy: that it makes for a good explanation, or at least an explanation with which the interlocutor is likely to be satisfied.

If quality of explanation drives analogy use, can we trace this to a specific attribute of analogical explanations? Research on explanation has identified *explanatory virtues*—a set of criteria for determining the quality of an explanation (Thagard, 1978; Harman, 1965; Mackonis, 2013; Glymour, 2014; Lombrozo, 2011). There is some disagreement about the precise set of explanatory virtues but, generally, three virtues commonly appear: coherence, simplicity, and causality (Thagard, 1989; Lombrozo, 2007; Lombrozo & Carey, 2006; Zemla, Sloman, Bechlivanidis, & Lagnado, 2017). Are analogical explanations coherent, simple, and causal? On the first count—coherence—the answer is affirmative because the construction of an analogy requires components of the explanation to fit together (Zemla et al., 2017). But it is unclear whether analogical explanations are simple by the definition of using the fewest causes to explain a phenomenon (e.g., Lombrozo, 2007). In some ways, analogy is complex because it must establish base and target analogs, and sometimes explicitly states the relation between them. For example, take one parent's analogical answer to the question "Why do we have to eat?": "Just like Dad's phone needs charging or it would not work, we gain energy from eating." This seems more complex than the (equally good) non-analogical explanation: "We need energy, and eating is our primary way of obtaining energy." Another possible metric for the complexity of everyday explanations is their length; see Zemla et al. (2017) who studied the Reddit "Explain Like I'm Five." On this count, too, we found that parental explanations containing analogy were typically longer than those that did not. The simplicity-complexity axis interacts with the explanatory virtue of *causality*: while analogical explanations can be causal, as in the eating example above, the same causal relationship can often be stated explicitly (because we need energy) without using analogy. Indeed, a majority of the good (highly rated) non-analogical explanations that we received from parents were causal explanations.

A trade-off between simplicity and analogy's explanatory power could be one reason why, in Study 3, six-year-olds rated causal explanations and good analogical explanations equally highly. This is in contrast to their parents who particularly valued good analogical explanations. There is evidence that children prefer simple over complex explanations (Bonawitz & Lombrozo, 2007), so children's ratings could be viewed as aggregating the benefits of simplicity with the explanatory power of (possibly more complex) analogies. In this view, the benefits of an analogical explanation compensate for the complexity, and children are able to discern this benefit.

At the same time, it is remarkable that six-year-olds were able to explicitly rate good analogies as good explanations and bad analogies as bad explanations, no different from their parents' ratings. Once again, our instructions simply asked for rating explanations and made no mention of analogy. While a huge number of studies have documented that children's learning benefits from analogy (e.g., Christie, 2020; Christie et al., 2020, Goswami, 2013), to our knowledge ours is the first study that documents children's judgment on the value of analogy. That is, while children often benefit from analogy, prior research has not explored whether children are aware of what an analogy is or if they are sensitive to its use. Our results hint that six-year-olds can see the value of analogy—even when these analogies are somewhat organic, rather than the perfectly constructed A:B::C:D analogies. In the future it will be important to investigate whether children's explicit judgment of analogical explanation correlates with implicit learning outcomes of explanations, such as greater exploration (Danovitch et al., 2021) or requesting further information (Mills et al., 2019).

Ultimately, the motivation for spontaneously generating analogies is perhaps best explained by analogy theory itself (Gentner, 2003): it allows the learner to see how a novel event (the question at hand) is structurally similar to a familiar one. Such comparison makes an explanation better (Edwards et al., 2019) not only by recruiting things that children already know, but also by highlighting a common structure (Christie, 2020; Christie & Gentner, 2010). This broadens the scope of the explanation, lending its valence for future generalizations and discoveries (Williams & Lombrozo, 2013). Future studies should consider a fuller range of factors that motivate and impact spontaneous generations of explanatory analogies. We hope the present work will spur an interest in this area.

References

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. *arXiv preprint arXiv:1406.5823*.

Begolli, K., & Richland, L. (2016). Teaching Mathematics by Comparison: Analog Visibility as a Double-Edged Sword. *Journal of Educational Psychology*, *108*, 194–213. https://doi.org/10.1037/edu0000056

Bonawitz, E. B., & Lombrozo, T. (2007). Simplicity and Probability in Children's Causal Explanations. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *29*(29).

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

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5(2), 121–152.

Chouinard, M. M. (2007). Children's questions: A mechanism for cognitive development. *Monographs of the Society for Research in Child Development*, *72*, 1–126

Chouinard, M. M., Harris, P. L., & Maratsos, M. P. (2007). Children's Questions: A Mechanism for Cognitive Development. *Monographs of the Society for Research in Child Development*, *72*(1), i–129.

Christie, S. (2020). Multiple exemplars of relations. In *Language and Concept Acquisition from Infancy Through Childhood* (pp. 221-245). Springer, Cham.

Christie, S., Gao, Y., & Ma, Q. (2020). Development of Analogical Reasoning: A Novel Perspective from Cross-Cultural Studies. *Child Development Perspectives*, *14*(3), 164–170. https://doi.org/10.1111/cdep.12380

Corriveau, K. H., & Kurkul, K. E. (2014). "Why does rain fall?": Children prefer to learn from an informant who uses noncircular explanations. *Child Development*, *85*(5), 1827–1835.

Crowley, K., Callanan, M. A., Jipson, J. L., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent-child activity. *Science Education*, *85*, 712–732. doi:10.1002/sce.1035

Dagher, Z. R. (1995). Review of studies on the effectiveness of instructional analogies in science education. *Science Education*, *79*(3), 295–312.

Danovitch, J. H., Mills, C. M., Sands, K. R., & Williams, A. J. (2021). Mind the gap: How incomplete explanations influence children's interest and learning behaviors. *Cognitive Psychology*, *130*, 101421.

Dunbar, K. (2001). The analogical paradox: Why analogy is so easy in naturalistic settings yet so difficult in the psychological laboratory. *The Analogical Mind: Perspectives from Cognitive Science*, 313–334.

Dunbar, K., & Blanchette, I. (2001). The in vivo/in vitro approach to cognition: The case of analogy. *Trends in Cognitive Sciences*, *5*(8), 334–339.

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

Frazier, B. N., Gelman, S. A., & Wellman, H. M. (2016). Young children prefer and remember satisfying explanations. *Journal of Cognition and Development*, *17*(5), 718–736.

Gentner, D. (2002). Analogy in scientific discovery: The case of Johannes Kepler. In *Model-based reasoning* (pp. 21–39). Springer.

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

Gentner, D., Brem, S., Ferguson, R. W., Markman, A. B., Levidow, B. B., Wolff, P., & Forbus, K. D. (1997). Analogical reasoning and conceptual change: A case study of Johannes Kepler. *The Journal of the Learning Sciences*, *6*(1), 3–40.

Gentner, D., & Hoyos, C. (2017). Analogy and abstraction. *Topics in Cognitive Science*, *9*(3), 672–693.

Gentner, D., Rattermann, M. J., & Forbus, K. D. (1993). The roles of similarity in transfer: Separating retrievability from inferential soundness. *Cognitive Psychology*, *25*(4), 524–575.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology*, *12*(3), 306–355.

Goldwater, M. B., Gentner, D., LaDue, N. D., & Libarkin, J. C. (2021). Analogy Generation in Science Experts and Novices. *Cognitive Science*, *45*(9). https://doi.org/10.1111/cogs.13036

Goswami, U. (2013). The development of reasoning by analogy. In *The development of thinking and reasoning* (pp. 61-82). Psychology Press.

Glymour, C. (2014). Probability and the Explanatory Virtues. *The British Journal for the Philosophy of Science*, axt051, 1–14.

Greif, M. L., Nelson, D. G. K., Keil, F. C., & Gutierrez, F. (2006). What do children want to know about animals and artifacts? Domain-specific requests for information. *Psychological Science*, *17*, 455–459.

Harman, G. H. (1965). The inference to the best explanation. *The Philosophical Review*, 88–95.

Hofstadter, D. R. (2001). Analogy as the core of cognition. *The Analogical Mind: Perspectives from Cognitive Science*, 499–538.

Hofstadter, D. R., & Sander, E. (2013). *Surfaces and essences: Analogy as the fuel and fire of thinking*. Basic Books.

Hoyos, C., Horton, W. S., Simms, N. K., & Gentner, D. (2020). Analogical Comparison Promotes Theory-of-Mind Development. *Cognitive Science*, *44*(9), e12891. https://doi.org/10.1111/cogs.12891

Keane, M. (1987). On retrieving analogues when solving problems. *The Quarterly Journal of Experimental Psychology*, *39*(1), 29–41.

Kemler Nelson, D. G., & O'Neil, K. (2005). How do parents respond to children's questions about the identity of artifacts? *Developmental Science*, *8*, 519–524.

Kurkul, K. E., & Corriveau, K. H. (2018). Question, explanation, follow-up: A mechanism for learning from others? *Child Development*, *89*(1), 280–294.

Leech, K. A., Haber, A. S., Jalkh, Y., & Corriveau, K. H. (2020). Embedding scientific explanations into storybooks impacts children's scientific discourse and learning. *Frontiers in Psychology*, *11*, 1016.

Lombrozo, T. (2007). Simplicity and probability in causal explanation. *Cognitive Psychology*, *55*(3), 232–257.

Lombrozo, T. (2011). The instrumental value of explanations. *Philosophy Compass*, *6*(8), 539–551.

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

Lorenz, K. Z. (1974). Analogy as a Source of Knowledge. *Science*, *185*(4147), 229–234. JSTOR.

Mackonis, A. (2013). Inference to the best explanation, coherence and other explanatory virtues. *Synthese*, *190*(6), 975–995.

Medin, D. L., Goldstone, R. L., & Gentner, D. (1993). Respects for similarity. *Psychological Review*, 100(2), 254.

Mills, C. M., Legare, C. H., Bills, M., & Mejias, C. (2010). Preschoolers use questions as a tool to acquire knowledge from different sources. *Journal of Cognition and Development, 11*, 533–560.

Mills, C. M., Sands, K. R., Rowles, S. P., & Campbell, I. L. (2019). "I want to know more!": Children are sensitive to explanation quality when exploring new information. *Cognitive Science*, *43*(1), e12706.

Richland, L. E., & Simms, N. (2015). Analogy, higher order thinking, and education. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*(2), 177–192.

Shtulman, A., & Checa, I. (2012). Parent-child conversations about evolution in the context of an interactive museum display. *International Electronic Journal of Elementary Education*, *5*, 27.

Thagard, P. R. (1978). The best explanation: Criteria for theory choice. *The Journal of Philosophy, 1978*, 76–92.

Thagard, P. (1989). Explanatory coherence. *Behavioral and Brain Sciences, 12*, 435–502.

Trench, M., & Minervino, R. A. (2015). The role of surface similarity in analogical retrieval: Bridging the gap between the naturalistic and the experimental traditions. *Cognitive Science*, *39*(6), 1292–1319.

Valle, A. (2009). Developing habitual ways of reasoning: Epistemological beliefs and formal emphasis in parent-child conversations. *Journal of Developmental Processes*, *4*, 82–98.

Willard, A. K., Busch, J. T., Cullum, K. A., Letourneau, S. M., Sobel, D. M., Callanan, M., & Legare, C. H. (2019). Explain this, explore that: A study of parent–child interaction in a children's museum. *Child Development*, *90*(5), e598–e617.

Williams, J. J., & Lombrozo, T. (2013). Explanation and prior knowledge interact to guide learning. *Cognitive psychology*, *66*(1), 55-84.

Zemla, J. C., Sloman, S., Bechlivanidis, C., & Lagnado, D. A. (2017). Evaluating everyday explanations. *Psychonomic bulletin & review*, *24*(5), 1488-1500.