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Children's Use of Analogy During Collaborative Reasoning

Tzu-Jung Lin and Richard C. Anderson
Center for the Study of Reading, University of Illinois at Urbana-Champaign

John E. Hummel
Department of Psychology, University of Illinois at Urbana-Champaign

May Jadallah
Illinois State University

Brian W. Miller, Kim Nguyen-Jahiel, and Joshua A. Morris
Center for the Study of Reading, University of Illinois at Urbana-Champaign

Li-Jen Kuo
Northern Illinois University

Il-Hee Kim
Indiana University–Purdue University Fort Wayne

Xiaoying Wu
Center for the Study of Reading, University of Illinois at Urbana-Champaign

Ting Dong
Uniformed Services University of the Health Sciences

This microgenetic study examined social influences on children's development of analogical reasoning during peer-led small-group discussions of stories about controversial issues. A total of 277 analogies were identified among 7,215 child turns for speaking during 54 discussions from 18 discussion groups in 6 fourth-grade classrooms (N = 120; age M = 10.0, SD = 0.6). Use of analogy was found to spread among the children in discussion groups and occur at an accelerating rate, primarily because of the increasing use of novel analogies. Relational analogies with shared surface features triggered purely relational analogies during the next 2 speaking turns, showing a trend of relational shift. These results provide distinctive new evidence for the importance of social interaction in an aspect of cognitive development.

Presumably analogical reasoning develops as children experience analogies over extended periods of time in social settings in the home, school, and community, but to our knowledge social influences on children's ability to understand and produce analogies have not been systematically documented. Most of the previous research on children's analogical reasoning has consisted of short-term, cross-sectional, experimental studies examining individual children one at a time (e.g., Goswami, 1991; Kotovsky & Gentner, 1996). The current study aimed to extend previous research by investigating whether dynamic moment-by-moment changes in children's use of analogy in a real-life collaborative context can be traced.

Sociocultural theories (see the review by Göncü & Gauvain, 2012) postulate that learning occurs when children get to play a part in a collective setting, where they can enact existing knowledge and thinking skills and participate at the growing edge of their competence. By these accounts, internalization through social interaction is the force driving individual cognitive development. To explain the mechanism of learning through social interaction, the concept of the zone of proximal development (Vygotsky, 1978) provides a general theoretical framework. This theory proposes that children's cognitive abilities are likely to progress from the actual developmental level to the potential developmental level

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The analysis reported in this article is based on a set of video transcripts also used in Li et al. (2007)—Emergent Leadership in Children's Discussion Groups—and Jadallah et al. (2011)—Influence of a Teacher's Scaffolding Moves During Child-Led Small-Group Discussions.

Correspondence concerning this article should be addressed to Tzu-Jung Lin or Richard C. Anderson, Center for the Study of Reading, 51 Gerty Drive, Champaign, IL 61820. Electronic mail may be sent to tlin27@illinois.edu or csrrca@illinois.edu.

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through the assistance of adults or in collaboration with competent peers. In this formulation, asymmetry of knowledge or skills is the lever for knowledge or skill transmission (Leman & Oldham, 2005). That is, in peer collaboration, children who have better cognitive skills serve as models for those who are less skilled. Previous studies have suggested that learning emerges from peer collaboration because of the joint effort and attention by which peers reach reciprocal understanding (Barron, 2003), the need to explicate procedures or concepts that individuals would have left unstated if working by themselves (Ellis, 1997), the process of discovering alternative ideas and the limitations of one's own thinking (Dunbar, 1997), and the opportunity to observe and emulate more competent partners (Azmitia, 1988).

Language is an important mediator for proximal development (Gauvain, 2001). From a Vygotskian viewpoint, learning how to regulate higher psychological functions such as analogical reasoning starts in the give and take of people talking with each other (cf. Göncü & Gauvain, 2012). When thoughts are verbalized, tentative and fluid ideas can possibly be transformed into crystallized and explicit forms. These externalized ideas shape both listeners' and speakers' internal thoughts (Winsler, Diaz, & Montero, 1997). For instance, Teasley (1995) found that fourth-grade students who produced talk when working in dyads on a scientific reasoning task had better task performance than students who worked alone or students who did not produce talk in dyads. Talk in dyads also tended to be more interpretive rather than descriptive, as compared to talk of students working alone. Following this logic, generating analogies in dialogue may assist the speakers as well as the listeners in understanding and producing analogies.

Regrettably, classroom environments that give children abundant opportunities to observe, practice, and internalize thinking tools through free-flowing interaction with their peers and teachers are not common. Teachers control classroom talk with seldom-broken strings of questions. Student answers often consist of only a word or a phrase (Cazden, 2001). In many classrooms, they have little opportunity to express extended ideas, ask questions, redirect the topic, or otherwise take initiative. Nystrand, Wu, Gamoran, Zeiser, and Long (2003) analyzed 1,151 instructional episodes from 200 eighth- and ninth-grade English and social studies classes. Only 66 episodes contained even one ''dialogic spell,'' or interval of discussion in which an in-depth exchange of ideas took place. The dialogic spells that did occur occupied only a few fleeting moments, for instance, averaging 42 s in eighth-grade social studies and 15 s in ninth-grade English.

Collaborative Reasoning (CR) is an open-format, peer-led approach to discussion intended to improve the quality of classroom talk, to stimulate critical reading and thinking, and to be personally engaging (Anderson, Chinn, Waggoner, & Nguyen, 1998). CR provides a sustained collaborative context in which small groups of children try to collaboratively come up with a good solution to a controversial issue, hereafter termed the *big question*, raised by a story they have read. Stories cover practical, ethical, or personal dilemmas, or child-friendly public policy or scientific issues. Children take individual positions on the issue, actively present reasons and evidence for their positions, and challenge each other when they disagree. Children operate the discussion as independently as possible. They speak freely without raising their hands to be selected by the teacher. The teacher sits outside the group, offering coaching only when necessary.

Research indicates that rate of student talk almost doubles during CR, as compared to baseline discussions in the same classrooms, and that students more frequently elaborate text propositions, make predictions, use text evidence to support opinions, and express alternative perspectives (Chinn, Anderson, & Waggoner, 2001). There is evidence that ways of talking and thinking acquired during as few as four CR discussions can transfer to the writing of reflective essays about a story students have not previously read or discussed. As compared to controls, on average students who have participated in CR write essays that contain better developed arguments, more consideration of opposing perspectives, better developed counterarguments and rebuttals, and more use of text evidence (Reznitskaya et al., 2008).

Previous studies have shown that children use a variety of *argument stratagems* during CR. An argument stratagem is defined as a recurrent rhetorical form that embodies a reasoning strategy or serves a social function in a discussion (Anderson et al., 2001). Examples of argument stratagems are ''What do you think [CLASSMATE]?'' and ''If [ACTION] then [BAD CONSEQUENCE] so [NOT ACTION]'' where the capitalized and bracketed words are place holders for context specific information with which the speaker instantiates the stratagem. An interesting discovery from previous research is that the use of argument stratagems *snowballs* (Anderson et al., 2001). That is, once an innovative child

has introduced a useful stratagem into a discussion, it tends to spread to other children and occur with increasing frequency. The snowball phenomenon has been documented in face-to-face discussions among children in China and Korea (Dong, Anderson, Kim, & Li, 2008), as well as in the Midwestern United States (Anderson et al., 2001), and in online discussions (Kim, Anderson, Nguyen-Jahiel, & Archodidou, 2007).

The current study investigated the effects of participating in CR on cognitive development in the domain of analogical reasoning. Examples of children using analogies have been reported in several CR studies. Anderson, Chinn, Chang, Waggoner, and Yi (1997) described a student who used a relational analogy, arguing that taking a shortcut in a dogsled race was like taking drugs to enhance performance in a foot race. The central relational commonality between the two domains is *cheating to get ahead*. Though both domains involve sports competitions, the two domains share few surface similarities. Dong et al. (2008) found that Chinese and Korean students frequently made intertextual references in CR discussions, comparing and contrasting other stories to the story currently being discussed. These examples suggest that CR is a fertile site for the study of analogy among children.

The topic of analogy is important because analogy is seen as playing a central role in induction (Hummel & Holyoak, 1997), problem solving (Gick & Holyoak, 1983), language development (Goswami, 2008), and scientific discovery (Dunbar, 1997). In education, reasoning by analogy is seen as a powerful learning mechanism (Richland, Holyoak, & Stigler, 2004). Over the past two decades, many studies have examined instructional analogies to enhance children's learning (e.g., Glynn & Takahashi, 1998). However, only a few studies have focused on the mechanisms of change in children's ability to understand analogies in classroom settings (May, Hammer, & Roy, 2006).

A common definition of analogy involves drawing correspondences between elements of a novel *target* domain and elements of a familiar *source* or *base* domain (Gentner, 1983; Hummel & Holyoak, 1997). These correspondences or similarities can be based on common surface properties (e.g., mapping Jane in one situation to Susan in another because both are girls), first-order relations (e.g., mapping Jane to Bill because both are bound to the agent role of the *love* [*x, y*] relation), higher-order relations (i.e., relations among relations, such as *cause*: *love* [*x*, *y*], *give* [*x*, *y*, gift]) or any combination of these.

''Distant'' analogies involve matching the higher-order relations in two domains. However, research suggests that spontaneous analogies in the real settings are not restricted to distant analogies, and frequently involve surface similarity as well as relational correspondences (Dunbar, 1997; Trickett & Trafton, 2007). Surface similarity may impair analogical transfer when the surface-based interpretation conflicts in some way with deeper relational similarities. On the other hand, common surface features may play a role in locating meaningful base domains (Holyoak & Koh, 1987; Hummel & Holyoak, 1997) and in generalization in certain kinds of problem solving situations (Bassok, 1996). Bassok commented that surface similarities can promote sensemaking when people use them to ''infer, modify, or qualify the relations that take these objects as arguments'' (p. 57).

We considered it likely that analogies involving shared surface features would provide the starting point and the foundation for children's spontaneous generation of analogies, and unlikely that they could or would start with analogies that were purely relational in the structural sense. What counts is whether children are able to compare things in a manner that introduces new information or a new perspective that can enhance their conceptual understanding of a target problem. Hence, in the current study, analogies could involve a target and base from the same domain, which implies many shared surface features, or from different domains where few surface features were shared. Doing so allows us to observe whether children move from using surface-based analogies to using more abstract, relational analogies. This is important inasmuch as available evidence suggests that early, surface analogies play a role in children's eventual shift to more abstract relational analogies (Kotovsky & Gentner, 1996).

There is considerable evidence that children can reason by analogy starting at a young age (e.g., Smith, 1984), although such ability is limited by several factors including lack of relevant knowledge or other factors associated with age (e.g., Richland, Morrison, & Holyoak, 2006). The knowledge account of analogy development is encompassed by the *relational primacy theory* proposed by Goswami (1991). The theory asserts that the ability to recognize or process relational similarities is an innate device in human thinking. Analogical development depends on acquiring relational knowledge. That is, the theory proposes that children are capable of processing higher-order analogies as long as they have acquired sufficient relational knowledge.

An alternative account of analogical development is *relational shift theory* (Gentner & Rattermann, 1991), which proposes that analogical reasoning development evolves in a certain sequence: The ability to detect relational similarities is proceeded by the ability to detect surface similarities, and the shift occurs when sufficient amount of domain knowledge is acquired. This theory is similar to the relational primacy theory with respect to the emphasis on knowledge accretion. The difference between the two theories lies in the role of surface similarities in young children's analogical reasoning development. While relational shift theory asserts that ''there is a systematic evolution in the kinds of relational comparisons that can be made as knowledge within a domain deepens: from overall similarity to object similarity, to relational similarity, and finally, to higher-order relational comparisons'' (Rattermann & Gentner, 1998, p. 469), the relational primacy theory assumes no such developmental sequence.

The present study evaluates whether children's spontaneous use of analogy over multiple CR discussions conforms to the snowball pattern. That is, we investigate the hypothesis that analogies would spread from child to child, occur with increasing frequency, and evolve in several qualitative aspects. By spontaneous analogy, we mean the analogies that are self-initiated, not requested by the teacher or directly prompted by others. By intensively observing and coding each individual student's talk throughout many discussions, the current study aimed to identify temporal changes in analogy use, investigate potential factors that could affect changes in the frequency or quality of analogies, and explore the effects of analogy on subsequent rhetorical moves during discussions.

The use of analogies was expected to snowball because as children observe the pioneers in their group, they will see the rhetorical force of analogies in changing attitudes and feelings (see Thagard & Shelley, 2001). They, too, will want to be able to use this valuable rhetorical tool. It was anticipated that collectively the children would clarify and extend analogies, leading to a deeper understanding of the process of identifying structural relations between targets and bases. Novel analogies were expected to increase over time because of the joint engagement with ideas from multiple perspectives. Across a series of discussions of various ethical and practical dilemmas, we anticipated that children would abstract the essential characteristics of a successful analogy, enabling an ever-widening circle of children to understand and produce analogies.

The major qualitative feature of analogies that we anticipated might change over time was the structure of analogies—with the expectation that rate of use of abstract relational analogies would increase as children had more experience using analogies during CR discussions. Also examined were additional features of analogies that might change over time or interact with other features, as follows: *explicitness*—whether children convey analogies in a clear and complete way; *novelty*—whether children introduce new analogies as opposed to reiterating analogies that other children have already used; *functionality*—the rhetorical function of analogies, either to confirm and elaborate the argument of a previous speaker or to counter this speaker's argument; and *topic relevance*—whether analogies advance the discussion of the main topic or lead to a digression.

Method

Participants

Participants were 120 fourth-grade students (68 girls and 52 boys), who ranged in age from 8.5 to 12.3 years (M = 10.0, SD = 0.6), from six classrooms in four public schools in central Illinois. While there was an unexpectedly wide range of ages, only 6 students were below 9 or above 11 years old. These 6 students were distributed in four of the six classrooms. Preliminary analyzes did not show any effect of age on the use of analogy. Two classrooms were from a rural school. Four classrooms were from three urban schools. The sample included 2 Asian Americans, 4 Hispanic Americans, 45 African Americans, and 69 European Americans.

Procedure

Teachers participated in a 1-day workshop that covered guidelines for CR discussions and described instructional moves for facilitating the discussions. These instructional moves helped set up the norms of CR. On days discussions were held teachers received suggestions from research assistants who were participant observers in their classrooms.

Children within each of the six classrooms were divided into three heterogeneous groups with teacher's assistance, each a cross-section of the class with respect to gender, ethnicity, talkativeness, and achievement level. Ten students were redistributed to the other groups after the first two discussions due to behavior problems. Each group participated

in 2 CR discussions per week for 5 weeks, 10 discussions in total. All of the discussions were videotaped and transcribed. There were a total 180 discussions in the complete dataset.

Students were asked to read a story individually in class before a discussion. The teacher called one group at a time to discuss the story while the other students completed work at their seats. A CR discussion began with the teacher's review of CR guidelines and introduction of the big question. Students were told there was no right or wrong answer to the big question, but they had to make a best decision that considered both sides of the issue. They did not have to raise their hands to express their ideas, but they were reminded to show respect for their classmates. The discussion ended with a teacher-led debriefing session in which children discussed the strengths and weaknesses of today's discussion and how to make the next discussion better. On average, CR discussions were 17 min in length.

Data Analysis

The first, third, and ninth discussions of each discussion group were selected from the corpus of 180 discussions for the analysis of analogical reasoning. The data set thus contains 54 story discussions, 3 discussions of each of three groups in each of the six classrooms. We believe that the selected discussions were representative of the whole corpus. The story order was fixed across groups, with short, easy-to-read stories first and longer, harder stories later. The story used for the first discussion was *What Should Kelly Do* (Weiner, 1980). The story is about a girl, Kelly, who wants to win a painting contest, but her classmate Evelyn is the best painter in the school. On the day to submit their work, Kelly discovers that Evelyn has left her painting outside on the playground and it is beginning to rain. The big question is: Should Kelly tell Evelyn about her painting? The story for the third discussion was *A Trip to the Zoo* (Reznitskaya & Clark, 2001). The story is about two girls discussing whether or not they should join a field trip to a zoo. Lily is excited to see all kinds of animals in the zoo, but Anna thinks that zoos are not good for animals. The question is: Are zoos good places for animals? The story used in the ninth discussion, *The Gold Cadillac* (Taylor, 1998), is about an African American family who lived in the North of the United States. The father wanted to take his family to visit relatives in the South driving a brand new gold Cadillac, but the South was still racially divided at that time and the gold Cadillac might have aroused resentment or worse among Southern Whites. The question is: Was it the right decision to drive the family to the South in the gold Cadillac?

Identifying speaking turns. The discussions were transcribed using Transtool (Kumar & Miller, 2005) and then coded using NUD*IST 6 (QSR, 2002). The first step was inspecting speaking turns for completeness and meaningfulness. During a ''full turn,'' a speaker holds the floor while expressing one or more interpretable propositions. Fragmentary turns that fail to meet this criterion were set aside, except that short turns that were used to answer yes-no questions or to supplement another person's unfinished sentence were kept in the transcripts.

Coding analogies. In the first phase, a coder read over the transcripts to identify potential analogies. This broad search was supplemented with a keyword search. Key words used for searching potential analogies were variations of *same, like, similar, if you were, what if, pretend*. Potential analogies were then evaluated based on context and meaning. An analogy must consist of a comparison or mapping of a target domain to a base domain, including cases in which either the target or the base was not explicitly stated but could be easily inferred. Another coder independently coded 20% of the potential analogies. The intercoder percentage of agreement was 97% (Cohen's Kappa = .97). All the identified analogies were then coded for structure, functionality, novelty, explicitness, topic relevance, and effects on subsequent discussion moves, as described below.

Coding the structure of analogies. An analogy's structure was coded in terms of the level of similarity between the base and target domains. Two compared domains may share common or similar surface properties, relations, or both. Surface similarity refers to the matched or similar objects or object characteristics, such as size, length, color. Relational similarity refers to the same relation between two objects (first-order relation), or the same relation between relations (higher-order relation). Examples of common first-order relations shared by the target and the base are comparatives, such as bigger, higher, darker, or relationship of two people such as friendship, marriage, discipleship. Common higher-order relations are more systemic and abstract, such as causal and mathematical relations. If mappings were based on common surface features only, the comparison has the lowest level of structure, which we called the *surface-only* structure. Analogical mappings based on common first-order relations with the support of surface similarity were called *surface + first-order*

structure, whereas mappings of common first-order relations without the support of surface similarity were called *first-order* structure. If analogical mappings were based on higher-order relations, they must also share the same first-order relations. With the presence of surface similarity, such higher-order relational mappings were called *surface + first-order + higher-order* structure; without surface similarity, they were called *first-and-higher-order* structure. Distinguishing first-order structure from first-and-higher-order structure was challenging. Hence, the five categories were later merged into three categories—surface-only comparison, surface + relation analogy, and relation-only analogy—to enhance coding reliability. More examples of the structure coding are shown in Table 1. The intercoder percentage of agreement for 20% of the cases was 95% (Cohen's Kappa = .89).

Coding the rhetorical function of analogies. Analogies can be use to support or oppose an idea. Thus, an analogy can be classified in one of two categories: confirmational or refutational. A confirmational analogy was used to support or elaborate a position. A refutational analogy was used to counter or rebut a position. The intercoder percentage of agreement for 20% of the rhetorical function codings was 93% (Cohen's Kappa = .86).

Coding the novelty of analogies. Analogies were classified as new or old. An analogy was new if new information was introduced or a new structural mapping was formed between the target and base domains, which no child had mentioned before in a given discussion. An analogy was classified as old if it had been brought up previously by another child in the discussion. The intercoder percentage of agreement for 20% of the cases was 86% (Cohen's Kappa = .72).

Coding topic relevance. If an analogy was judged to be related to the big question, it was classified as an on-topic analogy. Otherwise it was an off-topic analogy. The intercoder percentage of agreement for 20% of the topic relevance codings was 98% (Cohen's Kappa = .85).

Coding explicitness. Although all the analogies identified in this study satisfied the condition that the correspondences of target and base was explicit or could be readily inferred, the degree of explicitness varied, which might influence the comprehension or effectiveness of analogies. An analogy is explicit if the correspondences of the target and base were conveyed explicitly and the purpose, or point, of the analogy was explicitly mentioned. In contrast, an analogy is implied when the analogical mappings were not explained or the conclusion or rhetorical purpose of the analogy was not stated. The intercoder percentage of agreement for 20% of the cases was 90% (Cohen's Kappa = .77).

Coding analogy effects. To explore the influence of analogies on subsequent discussion, we coded five successive turns after every turn expressing an analogy into one of the following categories: (a) simple agreement without reasons (e.g., yes, I agree); (b) simple disagreement without reasons (e.g., no, I don't agree with you); (c) agreement with elaboration; (d) clarification, restating current position or reason; (e) request for reasons; (f) counterargument to the analogy; (g) rebuttal for the analogy; (h) intrinsic termination, shifting topics with no apparent external reason; (i) external termination, shifting topics because of time limits or reasons beyond the students' control; and (j) teacher's move, including praise for analogy, clarification, request for reasons, counterargument, or rebuttal. If any of the five successive turns after an analogy was also an analogy, then five turns after the additional analogy were also coded. The intercoder percentage of agreement for 20% of the cases was 91% (Cohen's Kappa = .90).

Results

The 54 discussions contained 12,849 turns for speaking, including 3,061 turns of introduction, debriefing, and nonverbal behavior; 2,241 fragmentary turns; and 332 simple position turns (e.g., ''I think yes''). Excluding the foregoing turns, the final data set contains 7,215 complete and interpretable turns. Among the complete and interpretable turns, a total of 277 analogies were identified, with 48 of 54 discussion transcripts containing at least one analogy. On average, there were 5.13 analogies per discussion with a range of 0–22 analogies (discussion time ranged between 10 and 41 min). These analogies were generated by 78 (65%) students, and 73% (n = 57) of these analogizers generated more than one analogy. The other students (n = 42, 35%) failed to generate an analogy in any discussion.

Analogy Generation Across Discussions

A Poisson regression analysis using the generalized estimated equations (GEE) technique (Liang & Zeger, 1986) was performed to examine patterns of analogy generation across discussions. The GEE technique accounted for the dependence due to repeated observations of number of analogies and number of analogizers for each CR group. Results

Table 1
Examples of Surface Comparisons and Analogies With Different Types of Structure

Structure	Definition		Example
Surface-only	Matched or similar objects or object characteristics, such as size, length, color	Mark	And it would be like just being in a jail sometime somewhere, it will, um, they won't like it that much
		Jason	They (animals in the zoo) think they're like in jail cause of the bars and all that
Surface + first-order	The same relation between two objects with the support of surface similarity	Susan	It was her responsibility for her own picture. She shouldn't have left it out there (in the playground)
		Jessica	She probably forgot about it
		Grace	So? She forgot about it
		Paul	What if . . . what if you was out there?
Surface + first-order + higher-order	Same relation between relations with the support of surface similarity	Teacher	What kind of feelings?
		James	Sad ones
		Teacher	I don't understand. . . . Maybe you could explain it to us
		James	It's like, if your painting's outside in the rain and you didn't know, and you was looking for it, and you didn't know somebody knew, and you was asking everybody and they didn't know, you would feel sad
		Danny	They shouldn't go to the south because um some white people have prejudice of black people just because they have more money and stuff, and I know this black guy and he has more money than we do and he just goes out and buys new cars and he's a friend of my dad's. My dad doesn't say get away
First-order	The same relation between two objects such as bigger, or human relationship such as friendship	Mark	When I was at zoo, it was, one elephant had its tusk cut off
		Allen	Yeh, but you have to so you wouldn't get hurt
		Peter	But they weren't really cut all the way. They'll still grow back
		Jenny	But it's still kind of cruel. What, what if like somebody get your teeth?
		Alex	Pretend this (classroom) is like a cage. And who would rather be here or recess?
		Jim	Recess, that's true
First-and-higher-order	Same relation between relations, more systemic and abstract, such as causal and mathematical relations	Kathy	Would you rather stay home and be safe or would you rather go somewhere and be arrested or
		Alison	Get killed or something
		Mark	Yeah, just like if . . . pretend, pretend you're living in Afghanistan right now and all the Afghanistan people are out there with guns and stuff and you're living there and you'd be safe in a home or something. What if you just walked out there in front of everybody and then they would just start shooting at you. It's the same way
		Anne	I agree with that, because um you can't, it's the same way with books. Oh, this looks like just because it is in black and white I'm not going to read it. That's the same thing with people

showed the number of analogies children generated increased by 43% from the first to the third discussion ($z = 3.98$, $p < .001$), and increased by 63% from the third to the ninth discussion ($z = 2.77$, $p = .001$). The increase across discussions also reflected a higher percentage of children using analogies, which increased from 33% in the first discussion to 44% in the ninth discussion.

Features of Children's Analogies

With respect to the *structure* of analogies, there were 36 (13%) surface-only comparisons, 144 (52%) surface + relation analogies, and 97 (35%) relation-only analogies. With respect to the *novelty* of analogies, among the 277 analogies, 111 (40%) were old analogies, 53% of them repeated by the same analo-

gizer and 47% picked up and repeated or elaborated by other children. There were 166 (60%) new analogies, generated by 2.13 (SD = 1.06) different children per discussion.

With respect to *topic relevance*, 20 out of 277 analogies (7%) were coded as off topic. Off-topic analogies proved to be related to analogy structure. A chi-square association test showed a significant association between the structure of analogy and digression, $\chi^2(2) = 73.29,\ p < .001$. Surface-only comparisons were 33.57 times more likely to be off topic than surface + relation analogies, and were 33.93 times more likely to be off topic than relation-only analogies.

Regarding the *explicitness* of analogies, there were 177 (64%) explicit analogies and 100 (36%) implied analogies. A chi-square association test showed a significant relationship between analogy structure and explicitness, $\chi^2(2) = 13.94,\ p < .001$. As shown in Table 2, surface + relation analogies were 1.23 times more likely to be explicit than relation-only analogies, and were 4.02 times more likely to be explicit than surface comparisons. Surface-only comparisons were more likely to be implied than the other structures. This might be because the speaker assumed other children already knew what kinds of surface features made the base and target objects similar. For example, in the following excerpt, Helen used magazine covers to illustrate that Evelyn can always draw an excellent painting when she wants to, but Helen did not explicitly mention the common attribute between the magazine covers and Evelyn's paintings.

> Helen: But see Evelyn—Evelyn can make pictures that look like the magazine covers whenever she felt like painting.

Regarding the *rhetorical function* of analogies, there were 191 (69%) confirmational analogies and 86 (31%) refutational analogies. A chi-square test showed that refutational analogies were 1.71 times more likely to be explicit than confirmational analogies, $\chi^2(1) = 3.63,\ p = .05$. This suggests that the explicitness of an analogy may be conditioned on its rhetorical function.

Table 2
Number of Analogies as a Function of Analogy Structure and Explicitness

	Explicitness		
Structure	Explicit	Implied	Total
Surface-only	14	22	36
Surface + relation	100	44	144
Relation-only	63	34	97
Total	177	100	277

Temporal Changes in Analogy Generation

This section examines whether use of analogy *snowballed*, or propagated throughout CR discussion groups. We evaluated whether children can learn the process of generating analogies through social interaction with other children such that analogies are generated more frequently over time. To test the hypothesis, the time interval between each pair of successive analogies within a discussion was the dependent measure. The ordinal position of analogies and its quadratic form were the main predictor variables. Other potential factors such as novelty and explicitness of analogy were also examined. The time interval for the first analogy in a discussion was calculated by subtracting the time when the analogy occurred from the time when the discussion began after the teacher's introduction. Six transcripts were removed from the analysis because they contained no analogies.

The snowball phenomenon was examined using a generalized gamma mixed model in which discussion was treated as a random cluster effect, ordinal position of an analogy within discussions was a fixed effect, and the time interval between analogies was the dependent variable. A gamma distribution was assumed because this distribution ''arises naturally in processes [involving] the waiting times between Poisson distributed events'' (Weisstein, n.d.). Analogies beyond the 15th in a discussion were removed from the analysis because of the small number of occurrences.

Model 1 in Table 3 contains the ordinal position of analogies and its quadratic form. Results showed that the ordinal position of an analogy had a negative relation with amount of time between occurrences ($\beta_{linear} = -.34,\ t = -5.17,\ p < .001$). The quadratic relation between the two factors was also significant ($\beta_{quadratic} = .001,\ t = 3.07,\ p < .005$), indicating a leveling off in the decline of time between later occurrences of analogies. Figure 1a shows that the first analogy was likely to occur 282 s after discussion began. Given that an analogy had occurred for the first time, the next analogy was likely to occur in about 195 s, and the third analogy 164 s after the second. Thus, the results are consistent with the hypothesis that the use of analogies would snowball: Over the course of a discussion analogies occurred with increasing frequency.

Table 3
Generalized Gamma Mixed Regression Models of the Analogy Snowball Phenomenon

Model parameter	Estimate	*SE*	*df*	*t*
Model 1				
Ordinal position	−0.34	0.07	221	−5.17***
Ordinal Position × Ordinal Position	0.01	0.005	221	3.07**
Model 2				
Ordinal position	−0.23	0.07	211	−3.30**
Ordinal Position × Ordinal Position	0.01	0.005	211	1.92
New analogy (1 = new, 0 = old)	0.78	0.15	211	5.05***
Model 3				
Ordinal position	−0.11	0.09	210	−1.21
Ordinal Position × Ordinal Position	0.004	0.005	210	0.84
New analogy (1 = new, 0 = old)	1.34	0.30	210	4.49***
New analogy × Ordinal Position	−0.09	0.04	210	−2.11*

*$p < .05$. **$p < .01$. ***$p < .001$.

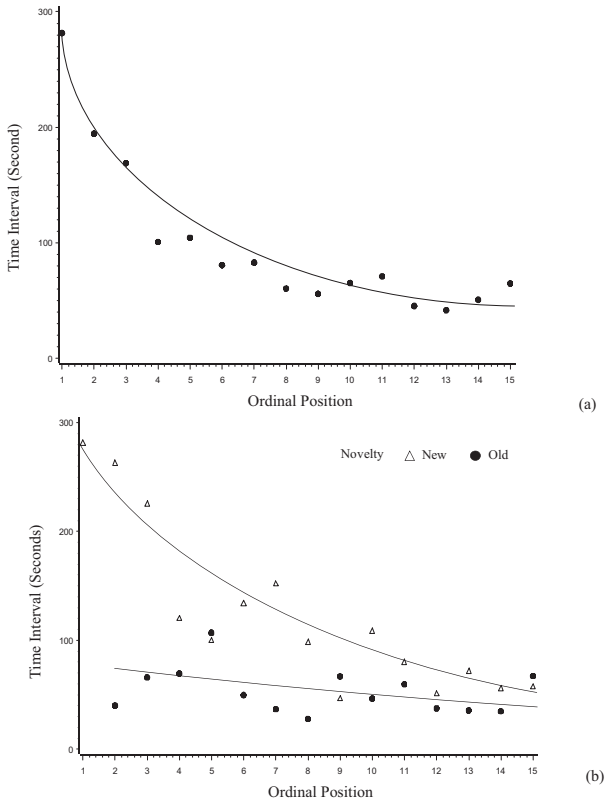

Figure 1. (a) Average time interval between successive pairs of analogies. (b) Average time interval between successive pairs of new and old analogies.

Whether an analogy was new or old was entered in regression Model 2. The time interval between two analogies was strongly related to the novelty of the second analogy ($\beta_{new} = .78$, $t = 5.05$, $p < .001$). Once an analogy was introduced in a discussion, children more promptly repeated or elaborated the analogy as compared to generating a new analogy. The snowballing of analogy use, however, was mainly attributable to new analogies. Model 3 documented a significant interaction of novelty and the ordinal position of analogies ($\beta_{New \times Ordinal\ Position} = -.09$, $t = -2.11$, $p < .05$), while the main effect of ordinal position and its quadratic were no longer significant. As can be seen in Figure 1b, the decline in time between analogies was almost entirely due to the increasing rate of new analogies.

Next, whether there were explicit comparisons between the target and base of the second analogy was entered in the regression model. The result showed that explicitness did not significantly predict the time interval between analogies, indicating that children generated explicit and implied analogies equally promptly. Event string length, or number of analogies in a discussion, was found to have a marginally significant and negative relation with time interval. Since the results did not change when the event string length variable was entered, this variable was dropped from the model.

An example of three concatenated analogies is shown in the following excerpt. Alex first generated an analogy about a person being locked in a cage. In response to Alex's question, Stacy elaborated the analogy expressing how she would feel if she were locked up in a cage. Then Emma presented a new analogy with minimal surface similarity to the previous analogy.

> Alex: Yeah, if you're locked up in the cage, how would you feel?
>
> Stacy: Yeah, I wouldn't like being locked up in the cage, that would not feel right.
>
> Emma: Cause it's like, your mom locking um you being punished or something, and your mom locking you in your room for a whole week.

Event history analysis was utilized as an alternative approach for examining the snowball phenomenon. The purpose of the alternate analysis was to be sure there was no distortion in findings due to censoring. In the context of the present study, censoring happened when discussions were brought to a close. When a discussion ends, it is

indeterminate whether there would have been other analogies or at what time intervals.

Because the event history structure of analogies incorporates a natural sequence of repeated analogy events clustered within discussions, the Prentice, Williams, and Peterson (PWP; 1981) conditional gap-time model was selected for the analysis. In our study, the PWP analysis entailed sequences of analogy events clustered by discussion and stratified by analogy order. The dependent variable is the time interval between successive pairs of analogies. Analogies beyond the 15th were not analyzed due to the small number of discussions in which more than 15 analogies occurred. Classroom, entered as a set of dummy variables, was employed as a covariate. Table 4 shows that the time between successive occurrences of analogies decreased as the ordinal position of an analogy within a discussion increased, which corroborates the previous snowball analysis employing generalized gamma regression. Interestingly, the survival function estimates were approximately constant over 15 occurrences, indicating that once one analogy occurred in a discussion successive analogies were likely to occur with about the same probability but at shorter and shorter time intervals. Classroom did not have a significant effect.

Table 4
Mean Time Intervals, Survival Function Estimates, and Cumulative Hazard Estimates of Analogy Events as a Function of the Number of Analogies Within Discussions

Number of analogies	Discussions with ≥ *N* analogies	Mean time interval	Mean survival function estimate	Mean cumulative hazard function estimate
1	48	281.65	0.51	0.89
2	39	194.62	0.53	0.81
3	31	169.07	0.53	0.79
4	26	101.00	0.53	0.84
5	22	104.64	0.52	0.85
6	19	80.95	0.51	0.86
7	15	83.13	0.56	0.79
8	13	60.69	0.51	0.87
9	11	56.09	0.50	0.85
10	10	65.40	0.49	0.91
11	9	71.22	0.47	0.90
12	7	45.57	0.51	0.78
13	6	41.83	0.49	0.86
14	4	51.00	0.57	0.67
15	4	65.00	0.45	1.00

Spread of Analogies From Child to Child

Table 5 shows that the average number and percentage of different children in a group who used an analogy increased as a function of number of analogies in a discussion, though the progression reached its maximum when there were nine analogies in a discussion. The table indicates that more frequent analogy use was *not* due to repeated use by the same children, but instead that analogy use was widely distributed among the children.

The mean numbers of new analogies in the first, third, and ninth discussions were 2.73, 2.88, 4.35, respectively, showing an increasing trend of new analogy generation across discussions. As the number of new analogies increased, the number of different children who generated new analogies also increased, suggesting that through social interaction more and more children were able to generate new analogies.

Given that the snowball phenomenon was primarily due to the increasing rate of new analogies, we further examined whether new analogies were generated by the same analogizers or addditional children. Every analogy (except for the first) in a discussion was assigned a ''new analogizer'' code if it was generated by a child who had not yet generated any analogy in this discussion. If the child had generated an analogy before, the analogy was assigned a ''repeat analogizer'' code. A two-way chi-square test showed that novel analogies were more likely to be generated by new analogizers than repeat analogizers, $\chi^2(1) = 5.22, \quad p < .05$),

Table 5
Number and Percentage of Children Who Use an Analogy as a Function of the Number of Analogies Generated in a Group

Number of analogies per discussion	Mean number of analogizers	Mean percentage of group
1	1.00	0.16
2	1.38	0.22
3	2.40	0.38
4	2.75	0.44
5	3.00	0.46
6	3.25	0.43
7	3.50	0.59
8	4.50	0.69
9	5.00	1.00
10	6.00	0.86
11	4.00	0.66
12	4.00	0.80
13	3.50	0.70
>15	4.75	0.75

indicating that the snowball phenomenon is primarily attributable to progressively more children generating new analogies.

Sequence of Analogies as a Function of Structure

A lag sequential analysis (Bakeman & Gottman, 1997) was used to examine the sequence of analogies with regard to structure. The goal of lag sequential analysis is to find out whether there is any systematic pattern in the sequencing of events beginning with a given or criterion event. This analysis outputs the transitional probability (TP) that a target event occurs given the criterion event has occurred. The target event can be immediate (Lag 1), after one intervening event (Lag 2), after two intervening events (Lag 3), and so forth. This analysis examined the sequence of analogies at Lag 1 and Lag 2. Nonanalogy speaking turns were coded as *other*. Consecutive codes were allowed to repeat. The set of 7,215 full speaking turns was entered in the analysis. Results showed that at Lag 1 analogies tended to trigger other analogies with the same structure. A surface + relation analogy increased the likelihood of another surface + relation analogy in the next turn for speaking (TP = .11, $p < .001$, Yule's $Q = .74$). Similarly, after a relation-only analogy, another relation-only analogy was more likely to occur in the next turn (TP = .06, $p < .001$, Yule's $Q = .67$). Importantly, surface + relation analogies increased the likelihood of subsequent analogies at the relation-only level (TP = .05, $p < .001$, Yule's $Q = .60$), while surface-only comparisons did not initiate such a relational-shift.

The Lag 2 sequence was similar to the sequence at Lag 1. An analogy was likely to trigger another analogy with the same structure after an intervening event (surface similarity $\rightarrow$ surface similarity, TP = .08, $p < .001$, Yule's $Q = .90$; surface + relation $\rightarrow$ surface + relation, TP = .07, $p < .001$, Yule's $Q = .59$; relation-only $\rightarrow$ relation-only, TP = .11, $p < .001$, Yule's $Q = .83$). A surface + relation analogy also increased the likelihood of a relation-only analogy at Lag 2 (TP = .04, $p < .001$, Yule's $Q = .54$).

Rhetorical Moves Triggered by Analogies

This analysis explored the effects of analogy on students' rhetorical moves during CR. A lag sequential analysis was performed on five successive turns after every turn containing an analogy. The number of rhetorical categories in the coding scheme was reduced from 12 to 7 to enhance statistical sensitivity. New and old analogies were merged into *Analogy*. Simple agreement and elaboration were merged into *Agreement-Elaboration*. Simple disagreement and counterargument were merged into *Disagreement-Counterargument*. Clarification of reasons or positions and requests for reasons were combined as *Clarification*. External and internal terminations were merged into *Termination*. Homogeneity and stationarity assumptions were met after removing two outlier discussions, although excluding the two extreme cases did not change the overall pattern of the pooled results. The results shown here are therefore based on the pooled data.

Figure 2 shows the likelihoods of rhetorical moves occurring after an analogy. Agreement-Elaboration and Disagreement-Counterargument were the most frequent rhetorical moves following analogies, but the relative difference between the conditional

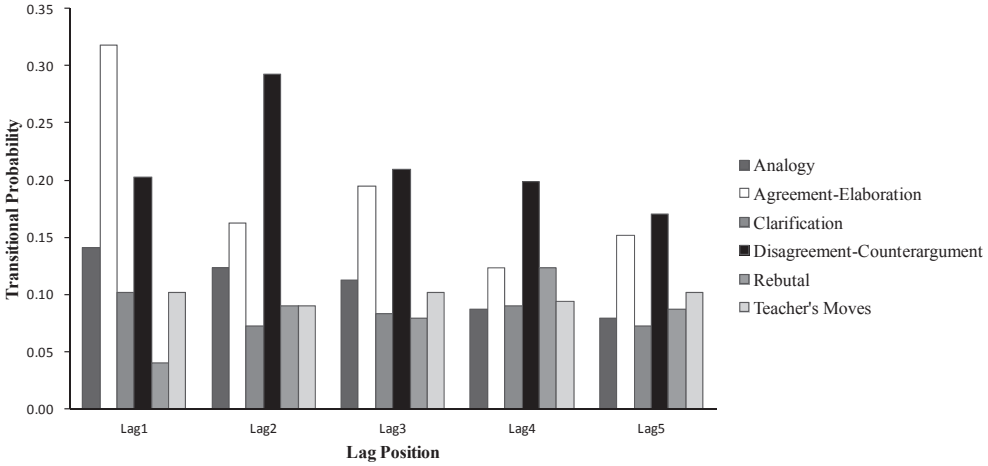

Figure 2. Rhetorical moves during five successive turns after analogies.
Note. All transitional probabilities were significant at $p = .001$.

probabilities of the two rhetorical moves changed over lags. At Lag 1, the TP of Agreement-Elaboration was higher than that of Disagreement-Counterargument. At Lag 2, Disagreement-Counterargument was more frequent than Agreement-Elaboration. After Lag 2, the two rhetorical moves became relatively even. Children presented more rebuttals at Lag 4. Termination had a low probability and thus is not shown in Figure 2. The low termination rate indicates that students were engaged by the process of analogical reasoning. Overall, the dynamic pattern of rhetorical moves following analogies suggests that analogy facilitates the flow of argumentation, and that multiple aspects of reasoning were triggered by the use of analogy.

Discussion

Taken together, the findings from the present study provide distinctive new evidence for the importance of social interaction in an aspect of cognitive development. The results showed that the use of analogy *snowballed*, or spread from child to child and occurred with increasing frequency. Our explanation is that once a child introduced an analogy in a discussion, other children had the opportunity to observe and appropriate this useful rhetorical tool. Analogies during CR discussions may serve as a language device children use to convey their perspectives to their classmates.

Moreover, the study documented qualitative changes in use of analogies over time. Whereas children often repeat or elaborate the analogies presented by previous speakers in a discussion, the snowball phenomenon was almost entirely due to the increasing rate of novel analogies (see Figure 1b). The increasing percentage of new analogies is noteworthy because generating a new analogy requires the ability to consider the issue from a different perspective that others have never mentioned in the discussion. This fact implies that the snowball phenomenon cannot be attributed to simple or shallow mimicry, but instead implies a deepening understanding of analogies.

Peer-led collaborative discussions appear to have provided an activity structure that amplifies social influences on analogical reasoning. Such discussions create a social milieu in which children collectively enrich the target domain by imagination and prediction, recalling personal experience, and applying principles known to them. Children often express what they would feel or how they would react if he or she were the protagonist, and they often ask their classmates to envision how they would feel or act if they stepped into the story world. Peer-led discussions afford children opportunities to exercise analogical retrieval, mapping, and inference from one domain to another. Analogy may be a conceptual tool for children to bring existing knowledge to bear on questions. As more knowledge is brought to the table, children are evidently able to refine their analogies. The process of jointly identifying the similarities and differences suggested by an analogy appears to cue children to closely examine relational features as well as surface similarities.

Analogies tended to progress from the surface + relation level to the pure relation level in the next two speaking turns, supporting the relational shift theory at the micro level of development (Gentner & Rattermann, 1991). These moment-by-moment changes in analogical development were documented using a microgenetic approach (Siegler & Crowley, 1991), and could not have been uncovered within any cross-sectional design.

Analogies triggered multiple rhetorical moves through at least five turns of discussion, implying that analogies introduced by peers are intellectually stimulating for children. Children used analogies equally frequently to confirm and to challenge one another, indicating that they were able to use analogies flexibly for different rhetorical purposes. The explicitness of an analogy was contingent on its rhetorical function. When children argued against other children's opinions, they tended to explicitly state the warrant or conclusion of the analogy. In contrast, when they generated analogies to elaborate other children's ideas, the warrant or conclusion were more likely to be left unstated, probably because these were assumed to be readily apparent from the previous speakers' contributions.

Children generated far more relational analogies than surface-only comparisons, but most often the relational analogies also involved shared surface features. These results are consistent with the Gentner, Rattermann, and Forbus (1993) finding that surface features shared by a base and a target would be more likely to lead a person to recall that base, compared to relational similarities without shared surface features. Holyoak and Koh (1987) proposed a similar idea in which analogy retrieval involves a summation of activation. Therefore, retrieving a base with many shared superficial features would be easier than retrieving a base with only shared core structural components. Surface + relation analogies may be more accessible than purely relational analogies—or distant analogies,

because surface features can facilitate visualization, which helps people uncover the otherwise hidden structure of a domain of knowledge (Clement, 1989). Relationships in common can then be bootstrapped from shared surface features.

The fact that students generated very few surface-only comparisons implies that in an argumentative environment students' thinking tends to be relational. The surface-only comparisons that did occur often led into a blind alley. Surface-only comparisons did *not* increase the likelihood of relational analogies in following speaking turns, tended to be inexplicit, and were far more likely than surface + relations analogies and relations-only analogies to lead to an off-topic digression.

Several issues remain unresolved. The results showed that children's use of analogy progressed across the discussions, but we cannot rule out the possibility of story effects, since stories were not counterbalanced. There were six discussions in which children failed to produce any analogies, and about one third of the students did not generate an analogy in any discussion. Three of the six no-analogy discussions occurred in the first session, two occurred in the third session, and the other one in the ninth. One reason for failures to generate any analogies in the first discussion, and perhaps the third, may be that children were not yet familiar with CR guidelines.

How well the ground rules for talk are set up by the teacher may affect the quality of discussion and the generation of analogies (Mercer & Wegerif, 1999). Teachers undoubtedly play a role in children's use of analogy, but the current study did not take into account analogies initiated by the teachers, or how teachers scaffolded children's use of analogy. Although CR was designed as a peer-controlled discussion forum, teachers' scaffolding has been found to have a profound effect on students' talk during CR (Jadallah et al., 2011). It is only reasonable to assume that teacher–student interaction would have an influence on analogy use. How teacher–student interaction and student–student interaction together influence children's use of analogy should be addressed in future research.

Whether the findings of the current study can be generalized to children of other ages is an unanswered question. Fourth-grade students were considered appropriate participants in a study of analogy in a collaborative setting in that research has shown that by the age of 10 children possess the level of communication and social skills to facilitate group talk (Teasley, 1995). Social experience increases dramatically during middle childhood, and a huge shift from adult–child interaction to more peer-to-peer interaction has been observed (Gauvain, 2001). With advancing age, factors such as friendship and social status may become increasingly important mediators of cognitive development during social interaction. Individuals in middle childhood have been reported to have better inhibitory control and greater working memory capacity than younger children (Richland et al., 2006), both necessary for skillful use of analogies, but their ability to integrate multiple relations is still below that of adults (Crone et al., 2009). Thus, the extent to which the analogical development of children of a certain age may improve during discussions with peers may be constrained by their social skills and cognitive level.

Failures of children to understand analogies are sometimes attributable to lack of knowledge, but in the present case children had enough knowledge to reason about the issues raised in the stories they read, and they were able to check each other during the give-and-take of discussion, allowing them to bridge an experience gap with adults. Another reason why children sometimes may not appreciate analogies at a relational level is that they are vulnerable to surface distractions, but in collaboration it seems they can help each other understand issues in deeper ways. Extending previous research on social collaboration and cognitive development, the present study suggests that experience in a stimulating social environment enabled children to exceed what might otherwise have been individual cognitive limits and collectively make rapid progress in understanding and producing analogies.

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