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Children's Use of Analogy during Collaborative Reasoning

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Abstract

Children's use of analogy was examined during peer-led small-group discussions using an approach called Collaborative Reasoning. Fifty-four discussions from 18 discussion groups in 6 fourth-grade classrooms were transcribed and searched for analogies. A total of 277 analogies were identified among 7,215 child turns for speaking. Analogies were coded for structure, rhetorical function, novelty, explicitness, and topic relevance. Use of analogy was found to *snowball*, or spread to other children and occur at an accelerating rate, primarily because of increasing use of novel analogies. Children generated many more relational analogies than surface-only comparisons. Relational analogies with shared surface features triggered purely relational analogies, showing a trend of relational shift. Multiple rhetorical moves, particularly moves involving elaboration and counterargument, were stimulated by analogies.

Keywords: Analogy, collaborative reasoning, snowball phenomenon

Children's Use of Analogy during Collaborative Reasoning

The purpose of this study was to investigate whether and how children learn to use analogies through interaction with peers in collaborative small-group discussions. The topic of analogy is important because analogy is seen as playing a central role in induction (Holland, Holyoak, Nisbett, & Thagard, 1986), problem solving (Gick & Holyoak, 1983), language development (Goswami, 2008), scientific discovery (Dunbar & Blanchette, 2001), and argumentation (Whaley, 1998). In education, reasoning by analogy is seen as a universal learning mechanism (Nokes, 2009; Richland, Zur, & Holyoak, 2007). Over the past two decades, many studies have examined instructional analogies to enhance children's learning (e.g., Glynn & Takahashi, 1998; Wong, 1993). 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; Richland, Holyoak, & Stigler, 2004). Moreover, while there is substantial psychological literature on analogical development, most of the studies have been short-term, cross-sectional, experimental studies primarily focused on younger children (e.g., Goswami, 1991; Kotovsky & Gentner, 1996). Virtually nothing has been done to understand whether older children's analogical reasoning will develop over an extended period of time in social contexts in which groups of children talk together.

A common but strict definition of analogy involves *mapping*, discovering which elements of a novel *target* domain correspond to elements of a familiar *source* or *base* domain (Gentner, 1983; Holyoak & Thagard, 1989; Hummel & Holyoak, 1997). These mappings 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. Most scholars who study analogy agree that to count as an analogy, the target and base domains must share at least first-order relations, and that an analogy is “better” to the extent that higher-order relations in the two domains are matched. Some researchers (e.g., Gentner, 1983; Gick & Holyoak, 1983; Holland et al, 1986) maintain that to be called a “true analogy” the target and base domains should lack surface similarity.

Earlier studies of analogical transfer and problem solving assumed the foregoing strict definition of analogy to investigate whether people can appreciate the abstract structural relationship between a source and target domain (e.g., Gick & Holyoak, 1983). However, recent studies conducted in non-laboratory settings have found that most of the spontaneous analogies that people generate are near/within-domain rather than far/between-domain analogies. For example, Dunbar (1997) observed scientists' use of analogies during biological laboratory meetings. Scientists frequently used biology-related analogies to solve experimental problems. Among 99 analogies identified, only two were non-biological. Trickett and Trafton (2007) observed nine scientists in eight data analysis sessions and identified only two far/between-domain analogies (i.e., comparisons based on structural or relational similarity), compared to 32 cases that fell into their “alignment” category (i.e., near/within-domain analogies). These studies suggest that spontaneous analogies in the real settings are not restricted to distant analogies. The fact that scientists used more near analogies than far analogies in lab meetings further suggests that even for mature adult experts, huge mental leaps are only made occasionally.

Surface similarities 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; Dunbar & Blanchette, 2001). Bassok commented that surface similarities can promote sense-making when people use them to “infer, modify, or qualify the relations that take these objects as arguments” (p. 57). In scientific discovery, for example, a type of analogy called the transformational analogy often leads scientists to the “Aha moment” (Clement, 1988). A transformational analogy forms a base domain by altering one or more attributes in the target domain. This type of analogy tends to be within-domain and surface-attached, and can be a very powerful analogy in scientific problem solving. In educational research, surface similarities are viewed as helping children to bootstrap from a concrete/surface level to a more abstract/relational level (C. L. Smith, 2007). As detailed later, these considerations played an important role in the coding scheme we developed to analyze children’s spontaneously-generated analogies.

It is not clear that the process of analogical mapping is qualitatively different when corresponding objects share surface features than when they do not (see, e.g., Hummel & Holyoak, 1997); it is simply that the mapping is more difficult to uncover in the latter case than in the former. Accordingly, we include mappings with shared surface features in our analysis, distinguishing them from mappings without shared surface features, as the anchor at the bottom of the hierarchy of kinds of analogies.

We considered it likely that analogies involved 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., L. B. Smith, 1984; Alexander, Willson, White & Fuqua, 1987), although such ability is limited by several factors including lack of relevant knowledge or other factors associated with age (Halford, Bain, & Mayberry, 1984; 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, 1988; Gentner & Rattermann, 1991), which proposes that analogical reasoning development evolves in a certain sequence: the ability to detect relational similarities is preceded 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.

Other researchers believe that the accumulation of relational knowledge may not overcome age-related maturational constraints such as the lack of inhibitory control or insufficient working memory capacity (e.g., Halford, Baker, McCredden, & Bain, 2005; Morrison, 2005). Richland et al. (2006) found that analogical development was constrained by cognitive complexity and distraction from salient surface features, even when the necessary relational knowledge was under control. Maturational constraints decreased with age. In scene analogy problems children at the age of 3-7 were easily distracted by surface features, but 9-11 year old children were less distracted by superficial features and less affected by cognitive complexity.

Perhaps equally important, or even more important, than growth in knowledge and maturation are social influences on analogical development. Often ignored in the analogy literature is the fact that children experience analogical reasoning in homes, schools, and community settings. Socio-cultural theories (Rogoff, 1995; Vygotsky, 1981; Wertsch, 1985) 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 through the assistance of adults or

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.

Language is an important mediator for proximal development (Gauvain, 2001; Nelson, 1996). When thoughts are verbalized, tentative and fluid ideas can possibly be transformed into crystallized and explicit forms. These externalized ideas in turn shape listeners' internal thoughts. 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 alone. Following this logic, generating analogies in dialogue may assist the speakers as well as the listeners to enhance their analogical reasoning abilities.

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 there was an in-depth exchange of ideas. The dialogic spells that did occur occupied only a few fleeting moments, for instance, averaging 42 seconds in eighth-grade social studies and 15 seconds 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 (Waggoner, Chinn, Yi, & Anderson, 1995). In CR, 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 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 and waiting to be selected by the teacher. Teachers sit 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 transfer to the writing of reflective essays about a story students have not previously read or discussed. As compared to controls, 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, Anderson, Dong, Li, I.-H. Kim, & S.-Y. Kim, 2008; I.-H. Kim et al, in press; Zhang, Anderson, & Nguyen-Jahiel, 2010).

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 short cut in a dog-sled 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 the domains both involve sports competitions, the two domains share few surface similarities. Dong, Anderson, I.-H. Kim, and Li (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. Analogies during CR discussions may serve as one of the language devices children use to convey their perspectives to their classmates. Analogy may be a conceptual tool for children to bring existing knowledge to bear on the target questions. As more knowledge is brought to the table during social interaction, children may be able to refine their analogies.

Previous studies have shown that children use a variety of *argument stratagems* during Collaborative Reasoning. 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 et al, 2008), as well as in the Midwestern United States (Anderson et al, 2001), and in online discussions (I.-H. Kim, Anderson, Nguyen-Jahiel, & Archodidou, 2007).

The present study evaluates whether children's spontaneous use of analogy over multiple Collaborative Reasoning discussions conforms to the snowball pattern. That is, we

investigated the hypothesis that analogies would occur with accelerating frequency and would evolve in several qualitative aspects. By spontaneous analogy, we mean the analogies that were self-initiated, not requested by the teacher, nor 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 major qualitative feature of analogies that we anticipated might change over time was the structure of analogies – with the expectation that rate of use abstract relational analogies would increase as children had more experience using analogies during Collaborative Reasoning discussions. Additional features of analogies were examined 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 extending 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 (67 girls and 53 boys), who ranged in age from 8 to 12 years ($M = 10.0$, $SD = 0.6$), from 6 classrooms in 4 public schools in central Illinois. 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 one-day workshop which 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, 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 two CR discussions per week for five weeks, ten 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 teacher's review of CR guidelines and an introduction of the big question. Students were then asked to say their names and state a position on 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 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 15 minutes in length.

Data Analysis

The first, third, and ninth discussion of each discussion group were selected from

corpus of 180 discussions for the analysis of analogical reasoning. The data set thus contains 54 story discussions, 3 discussions of each of 3 groups in each of the 6 classrooms. We believe that the selected discussions were representative of the whole corpus.

Experience has shown that the stories on which the discussions were based are interesting and comprehensible to children and lead to lively discussions. 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. These include back channeling, failed attempts to gain the floor, abandoned utterances, "I think, uh . . .", and interjected comments (see Chinn et al., 2001). Back channeling refers to short utterances such as "yeah," "OK," which show a person is attending to the main speaker. Failed attempts to gain the floor means that two people speak at the same time, and either one of them stops to let the other speaker finish or the main speaker continues talking without yielding the floor. An interjected comment is when a person makes a statement such as, "I don't agree," in the middle of an utterance by the main speaker, who continues speaking as if the interjection did not occur. In addition, the introduction and debriefing segments of a discussion, descriptions of non-verbal behavior (e.g., gestures, facial expressions), and transcribers' comments (about such matters as side conversations among children, announcements over the public address system) were removed from transcripts. 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. Coding proceeded in two phases. In the first phase, a coder read over the transcripts to identify potential analogies. This broad search was supplemented with a key-word 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/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 inter-coder percentage of agreement was 97% (Cohen's Kappa = .97). All the identified analogies were then coded for structure, function, 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 the target domain. 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 relationship between two objects (first-order relation), or the same relationship 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 analogical mappings were based on common surface features only, the analogy has the lowest level of structure, which we called the *surface-only* structure. Analogical mappings that were 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 three categories – surface-only similarity, surface+relation, and relation-only – to enhance coding reliability. More examples of the structure coding are shown in Table 1. The inter-coder percentage of agreement for 20% of the cases was 95% (Cohen's Kappa = .89).

[Insert Table 1 about here]

Coding the rhetorical function of analogies. Analogies can be used to support or oppose an idea. Thus, an analogy can be classified in one of two categories: confirmative or

refutational. A confirmative analogy was used to support or elaborate a position. A refutational analogy was used to counter or rebut a position. The inter-coder 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 the information or mapping had been brought up previously by other children in the discussion. The inter-coder 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 inter-coder 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 mappings 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 mappings 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 inter-coder 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, (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 inter-coder 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 to 22 analogies (discussion time ranged between 10 and 41 minutes). 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.

Further analyses of children's use of analogy addressed five topics, as follows: Analogy generation across discussions, features of children's analogies and interactions among these features, temporal changes in analogy generation, sequence of analogies as a function of structure, and rhetorical moves triggered by analogies.

Analogy Generation across Discussions

A Poisson regression analysis using the Generalized Estimated Equations technique (Liang & Zeger, 1986) showed that, after accounting for the dependence due to repeated observations, 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 reflected both a higher percentage of children using analogies, which increased from 33% in the first discussion to 44% in the ninth discussion, and more frequent use by those who analogized.

Features of Children's Analogies

With respect to the *structure* of analogies, there were 36 (13%) surface-only comparisons, 144 (52%) surface+relation analogies, 97 (35%) relation-only analogies. It is interesting that relational analogies with shared surface features were more numerous than relation-only analogies. The fact that students generated very few surface-only comparisons implies that in an argumentative environment students' thinking tended to be relational. These results are consistent with Gentner, Rattermann, and Forbus's (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 with 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.

With respect to the *novelty* of analogies, among the 277 analogies, 111 (40%) were old analogies, 53% of them repeated by the same analogizer and 47% picked up and repeated or elaborated by other children. There were 116 (60%) new analogies, generated by 2.13 (SD = 1.06) different children per discussion. While there is nothing wrong with a child

elaborating an analogy introduced by another child, the large percentage of new analogies is noteworthy because generating a new analogy requires the ability to consider the issue from a different perspective that others had never mentioned in the 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 ($\chi^2_{(3)} = 73.29, p < .001$). 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.

[Insert Table 2 about here]

Regarding the *rhetorical function* of analogies, there were 191 (69%) confirmatory analogies and 86 (31%) refutational analogies. A Chi-Square test showed that refutational

analogies were 1.71 times more likely to be explicit than confirmative analogies ($\chi^2_{(1)} = 3.63$, $df = 1$, $p = .05$). This suggests that the explicitness of an analogy may be conditioned 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.

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 Poisson mixed model in which student and discussion were treated as random cluster effects, ordinal position of an analogy within students within discussions was a fixed effect, and the time interval between analogies was the dependent variable. 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 relationship with amount of time between occurrences ($\beta_{\text{linear}} = -.13, t = -16.2, p < .001$). The quadratic relationship between the two factors was also significant ($\beta_{\text{quadratic}} = .004, t = 6.69, p < .001$), 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 seconds after discussion began. Given that an analogy had occurred for the first time, the next analogy was likely to occur in about 195 seconds, and the third analogy in 164 seconds after the second. Thus, the results are consistent with the snowball phenomenon: over the course of a discussion analogies occurred with increasing frequency.

[Insert Table 3 and Figure 1a about here]

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 ($\beta_{\text{new}} = .69, t = 31.86, p < .001$). 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 ($\beta_{\text{new} \times \text{ordinal position}} = -.04, t = -6.96, p < .001$), 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.

The time interval between analogies was not related to the explicitness of the second analogy, 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 relationship with time interval. Since the results did not change when the event string length variable was entered, this variable was dropped from the model.

[Insert and Figure 1b about here]

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 Daisy 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. |
| Daisy | 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 Poisson regression. Interestingly, the survival function estimates and cumulative hazard function

estimates were approximately constant over 15 occurrences, which indicates 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.

[Insert Table 4 about here]

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. Non-analogy 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 was likely to be followed by another surface+relation analogy immediately (TP = .11, $p < .001$, Yule's Q = .74). Similarly, a relation-only analogy was likely to be followed by another relation-only analogy (TP = .06, $p < .001$, Yule's Q = .67). Importantly, the use of 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 → surface similarity, $TP = .08$, $p < .001$, Yule's $Q = .90$; surface+relation → surface+relation, $TP = .07$, $p < .001$, Yule's $Q = .59$; relation-only → 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 $Q = .54$). The result supports our hypothesis that relational analogies with shared surface similarity plays a role in scaffolding a relation-only mapping, but surface-only similarity fails to show such a relational-shift effect.

Rhetorical Moves Triggered by Analogies

This analysis explored the effects of analogy on students' rhetorical moves during Collaborative Reasoning. 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 still 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 probabilities of the two rhetorical moves changed over lags. At Lag 1, the transitional probability 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.

[Insert Figure 2 about here]

General Discussion

A major finding of the present study is that children's use of analogy *snowballs* during collaborative peer-led discussions. Once a child introduces an analogy in a discussion, the use of analogies spreads to other children and analogies occur with increasing frequency. 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). This fact implies that the snowball phenomenon cannot be attributed to simple or shallow mimicry, but instead implies a deepening understanding of analogies. Taken together, the findings from the study provide distinctive new evidence for the importance of social interaction in an aspect of cognitive development.

The present study also showed that children generated far more relational analogies than surface-only comparisons, but most often the relational analogies also involved shared surface features. Analogy use tended to progress from the surface+relation level to the pure relation level in subsequent speaking turns, supporting the relational-shift theory at a micro level (Gentner & Rattermann, 1991). Surface+relation analogies had a higher frequency in the present study, and perhaps greater value. Surface+relation analogies may be more

accessible than purely relational analogies, or distant analogies, in that 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. Such an interpretation is supported by Holyoak and Koh (1987), who found that when a base and a target shared more surface features, the underlying structure of knowledge was more likely to be retrieved than when a base and a target shared few surface features.

Analogical reasoning with the support of surface similarities may make fewer cognitive demands than relational reasoning without surface similarities. This is because when common surface features are present, the analogizer would assume things at the surface level are the same, and therefore can spend more effort mapping relational similarities and less effort suppressing irrelevant surface features. This interpretation is consistent with the LISA model (Hummel & Holyoak, 1997), which predicts that formally difficult mappings can be reduced in their complexity if the correct mapping is facilitated by surface similarity. Conversely, they can be made even more difficult if the correct mapping is contradicted by surface similarity. Relying on surface features to access a relevant base problem may be a valuable and sometimes necessary heuristic (cf. Blessing & Ross, 1996). Most of the time surface features and the underlying structure of a problem are correlated (Sweller, 1980). Taking advantage of the easy-accessibility of surface similarity can create a short cut to a deeper level of thinking.

Whereas surface+relations analogies were frequent in the set of discussions analyzed in this paper, likely to be explicit, and pivotal in microdevelopment in the sense that they significantly increased the transition probability of a relation-only analogy in the following two speaking turns, surface-only comparisons were infrequent and those that did occur often

led into a blind alley. Surface-only comparisons did *not* increase the likelihood of relational analogies in following speaking turns. Surface-only comparisons tended to be inexplicit and were far more likely than surface+relations analogies and relations-only analogies to lead to an off-topic digression. These contrasting features and the moment-by-moment aspects of change in cognitive development were successfully demonstrated using the microgenetic approach (Siegler & Crowley, 1991), which cannot be accomplished within any cross-sectional design.

One thing worth mentioning is that a few off-topic analogies were immediately redirected by other children or the teacher. Although such social control was not systematically examined here, we can say that children generally seemed to try to make sense of analogies and critically examine their validity. The process of identifying similarities and differences suggested by an analogy appear to cue children to closely examine deep features as well as surface features (see Wong, 1993). Collaboratively, they enriched the target domain by imagination and prediction, recalling personal experience, and applying principles known to them.

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. We compared the teacher-student interaction styles between one discussion that did not generate any analogy and the discussion containing the most analogies. The contrast of these two discussions suggested that in the high-analogy discussion the children were more willing to talk because the teacher yielded the floor to students and asked occasional open-ended questions instead of more frequent short-answer questions. This teacher praised the children judiciously and appeared to request reasons at appropriate times. Although Collaborative Reasoning was designed as a peer-controlled discussion forum,

teachers' scaffolding has been found to have a profound effect on students' talk (Jadallah et al., 2010). 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 the future.

Our conjecture is that spontaneous child-generated analogies are better able to facilitate conceptual understanding than teacher-supplied analogies. Child-generated analogies may have high accessibility for children because children have shared perspectives and shared background knowledge. In the current study, 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 finding that analogies triggered multiple rhetorical moves through at least five turns of discussion implies that analogies introduced by peers are intellectually stimulating for children.

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 were setup by the teacher might have affected the quality of discussion and the generation of analogies (Mercer & Wegerif, 1999).

Perhaps the major force driving the analogical development observed in the present study was that Collaborative Reasoning discussions afforded children lots of opportunities to

exercise analogical retrieval, mapping, and inference from one domain to another. 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. In this sense, experience in a stimulating social environment may have enabled children to exceed what might otherwise have been individual cognitive limits.

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Table 1

Examples of Surface Similarity 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, and regular jail person being in a jail some time somewhere it will, um, they won't like it that much
		Mary	They think they're like in jail cause of the bars and all that
Surface+ first-order	the same relationship 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.
		Jessica	She probably forgot about it
		Grace	So? She forgot about she forgot about it.
		Paul	What if what if you was out there?
Surface+ first-order+ higher-order	same relationship 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 askin everybody and they didn't know, you would feel sad.
First-order	the same relationship between two objects such as bigger, or human relationship such as friendship	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.
		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?
First-and-higher-order	same relationship between relations, more systemic and abstract, such as causal and mathematical relations	Alex	Pretend this is like a cage. And who would rather be here or recess?
		Jim	Recess, that's true.
		Katherine	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	Anne	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.
		Anne	That's the same thing with people.

Table 2

Number of analogies as a function of analogy structure and explicitness

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

Table 3

Generalized Poisson mixed regression models of the analogy snowball phenomenon

Model parameter	Estimate	SE	df	t	
Model 1					
Ordinal position	-0.13	0.008	155	-16.20	***
Ordinal position × Ordinal position	0.004	0.001	155	6.69	***
Model 2					
Ordinal position	-0.06	0.009	154	-7.01	***
Ordinal position × Ordinal position	0.0004	0.0006	154	0.63	
New analogy (1 = New, 0 = Old)	0.69	0.02	154	31.86	***
Model 3					
Ordinal position	-0.005	0.012	153	-0.39	
Ordinal position × Ordinal position	-0.001	0.001	153	-2.14	
New analogy (1 = New, 0 = Old)	0.95	0.044	153	21.75	***
New analogy × Ordinal position	-0.04	0.006	153	-6.96	*

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

Table 4

Mean time intervals, survival function estimates, cumulative hazard estimates of analogy events as a function of the number of analogies within discussions

Number of Analogies	Discussions with $\geq N$ 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

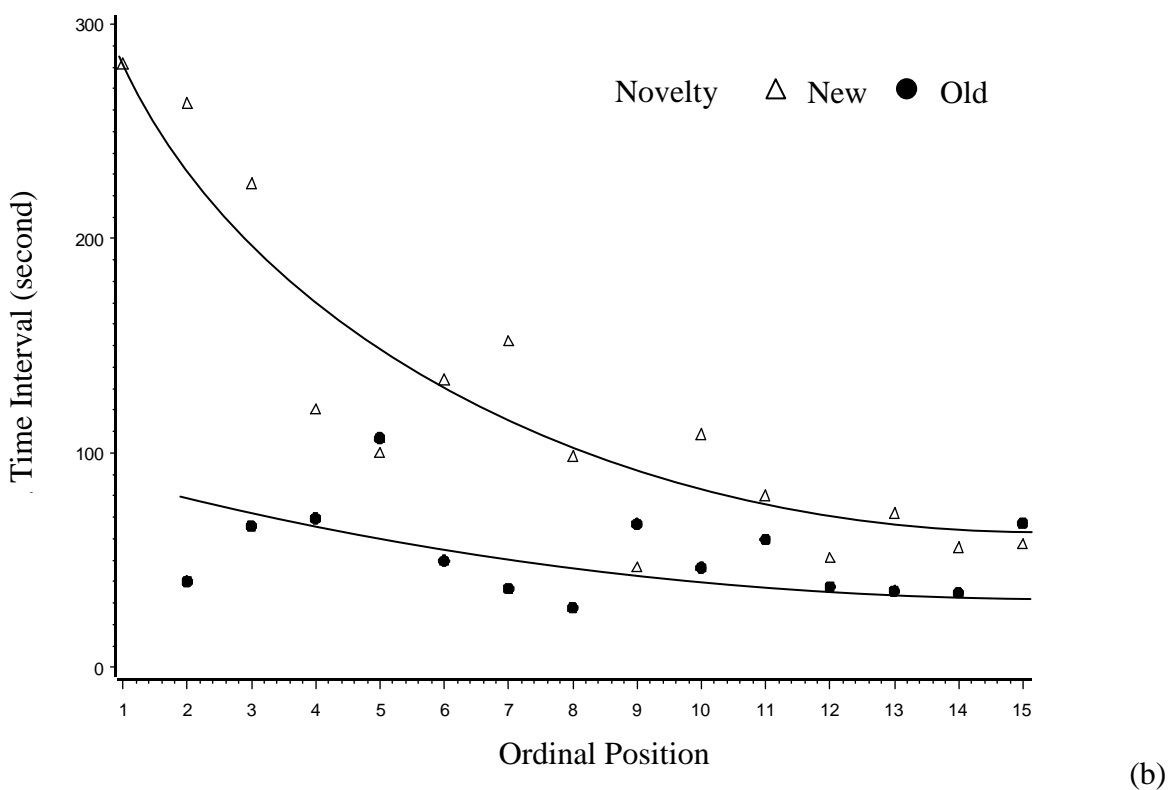
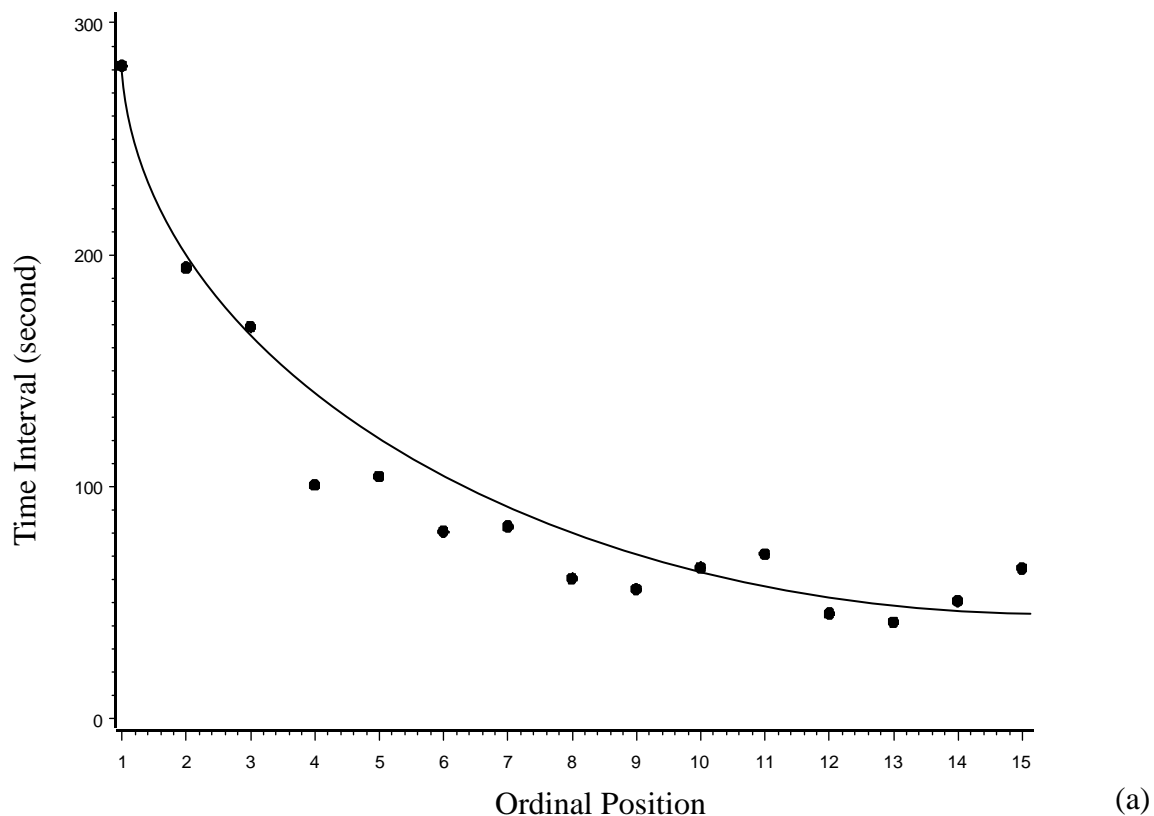


Figure 1. (a) Average time interval between successive pairs of analogies. (b) Average time interval between successive pairs of new and old analogies.

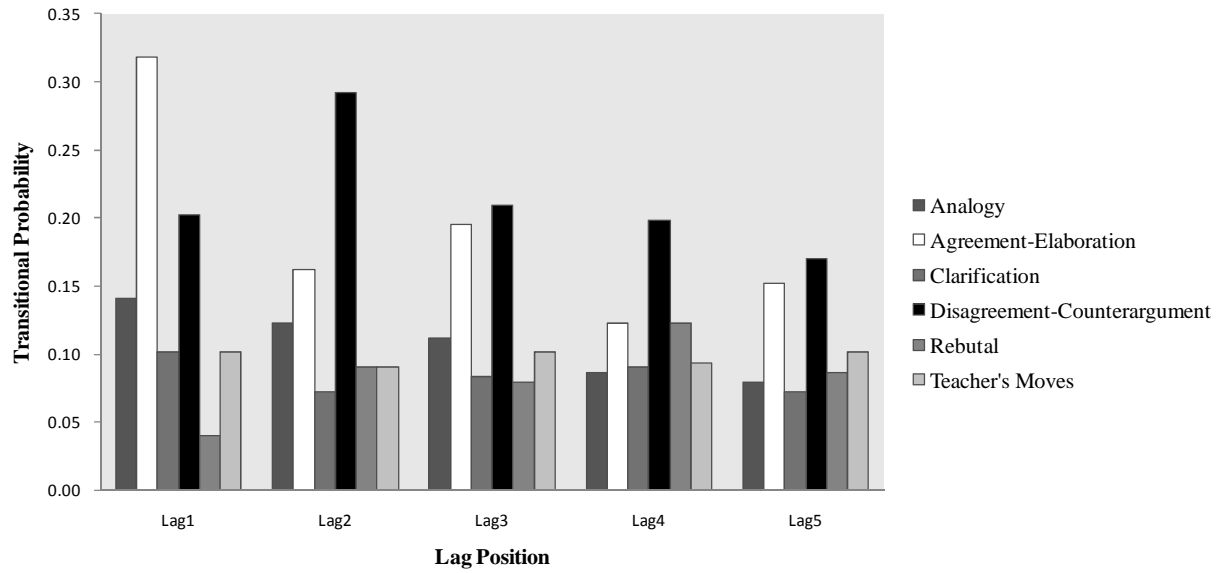


Figure 2. Rhetorical moves during five successive turns after analogies. All transitional probabilities were significant at $p = .001$.