Contemporary Educational Psychology 41 (2015) 83–97

Contents lists available at ScienceDirect

Contemporary Educational Psychology

journal homepage: www.elsevier.com/locate/cedpsych

Social influences on children's development of relational thinking during small-group discussions

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ARTICLE INFO

Article history:
Available online 16 December 2014

Keyword:
Relational thinking
Friendship
Peer status
Social network
Proximal development
Dialogic interaction

ABSTRACT

This microgenetic study strived to understand instantaneous peer influences on the moment-by-moment and session-by-session development of relational thinking within and across dialogic small-group discussions using an approach called Collaborative Reasoning. An analysis encompassing 32,511 turns for speaking during 176 discussions indicated that peer support and refutation influenced the development of relational thinking within (micro-level) and across (macro-level) discussions, and was mediated by friendship and peer status. Support was mainly mediated by friends and children with high status. Observing reciprocated friends' supportive talk encouraged students to generate confirmational relational thinking in the next turn for speaking. Refutation was mainly mediated by children with high status. Quiet students generated less refutation. The study documents the proximal effects of peer status and friendship on the social and cognitive dynamics of collaborative discussions.
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1. Introduction

Relational thinking is the ability to perceive, construct, and manipulate relations between concepts to form coherent schemas (Holyoak, 2012). Understanding the mechanisms by which this ability develops is crucial to understanding cognitive development, as relations are the building blocks of all kinds of knowledge (Dumas, Alexander, & Grossnickle, 2013). Previous studies of relational thinking highlight the importance of individual cognitive factors (e.g., Halford, Andrews, Dalton, Boag, & Zielinski, 2002; Gentner & Rattermann, 1991). So far, however, social influences on the development of relational thinking have received little attention.

The major goal of this study was to capture instantaneous social effects on moment-by-moment cognitive development during and across collaborative small-group discussions. The general working hypothesis was that large-scale changes in thinking depend upon many small steps that are made possible by recurrent patterns of productive dialogic interaction. The study modeled the time course of support and refutation that students offered each other during the give-and-take of a socially-supportive, cognitively-engaging small-group discussion approach called Collaborative Reasoning (Chinn, Anderson, & Waggoner, 2001), examined whether these elements of discussion were associated with the micro-development of relational thinking, and explored whether effects were mediated by peer relationships. We theorize that Collaborative Reasoning (CR) discussions provide a context where students can socialize their relational thinking through a dynamic co-construction and co-evaluation process (Anderson et al., 2001); the emphasis on social support in CR reinforces positive peer relationships, which contribute to socially harmonious and cognitively invigorating interaction.

Studies of cognitive development typically evaluate students' growth in terms of change in pre- and post-intervention assessments, which does not shed light on *how* and *when* students' cognitive skills progress, and especially what types of interaction bring about change. Little is known, for example, about whether friends are more willing to support or oppose each other, and

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http://dx.doi.org/10.1016/j.cedpsych.2014.12.004
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whether popular students contribute to or hinder group processes. The study employs the microgenetic method (Siegler, 2006). An essential feature of the method is that the density of observations is high relative to the rate of change in the phenomenon under investigation. As Siegler (2005) explains, "Learning tends to follow irregular paths involving regressions as well as progress, short-lived transitional approaches, inconsistent patterns of generalization, and other complexities. Because of this complexity, the only way to determine how children learn is to follow them closely while they are learning" (p. 770). The present study involved additional layers of complexity, beyond those in most previous microgenetic studies (e.g., Kuhn, Goh, Iordanou, & Shaenfield, 2008; Siegler & Svetina, 2002). Instead of the behavior of individual students, the collective action of groups of students was tracked. Instead of discrete trials under the control of the experimenter, the students freely controlled their own behavior.

1.1. Relational thinking in collaborative discussions

Relational thinking involves the ability to appreciate how things are connected (e.g., predator–prey relationship, kinship relationships), the ability to identify common structures among things with distinct surface features (Chi & VanLehn, 2012), and the ability to manipulate these relations to form systematic concepts or schemas (Hummel & Holyoak, 2005). The ability to recognize and manipulate complex relations enables students to perform many higher-order thinking functions, such as drawing inferences between premises and conclusions to reach logical coherence during reading, generating analogies in argumentation, identifying abstract mathematical principles, associating theory and evidence in scientific discovery. Relational thinking is fundamentally important to knowledge transfer and conceptual change (Holyoak, 2012; Schwartz, Chase, Oppezzo, & Chin, 2011).

Many individual cognitive factors have been found to contribute to developmental change (Gentner & Rattermann, 1991; Goswami, 1991; Halford et al., 2002; Loewenstein & Gentner, 2005; Richland, Chan, Morrison, & Au, 2010; Richland, Morrison, & Holyoak, 2006). Less is known about moment-by-moment development during a social process, how interpersonal factors influence the process, and how micro-level development contributes to macro-level development over days, weeks, or months.

Dialogic interaction is argumentative discourse in which participants all have rights to formulate arguments to support their own viewpoints and probe others to better understand or refute opposing viewpoints (Reznitskaya et al., 2009). A supporting argument embeds relational thinking when it involves reasons or evidence that justifies a claim. Similarly, a refutational argument is relational when counter-reasons or counter-evidence are provided. To generate a supporting or refutational argument, the learners must have some understanding of how ideas can be connected. Means for connecting ideas can be secured by appropriating relational thinking strategies encountered in dialogic talk.

We hypothesize that when students observe peers engage in a relational thinking strategy judged to have explanatory power or persuasive force, they are likely to emulate the strategy. We assume that students who frequently and successfully generate relational thinking serve as models for those who seldom do or do so less effectively. Subsequently, we suppose that as less-skilled students attempt relational thinking strategies, they are often provided with support by more competent peers. Exposure to various points of view prompts students to compare and contrast perspectives and identify gaps in understanding, which in turn is assumed to advance students' relational thinking. The current study explored the moment-by-moment time course of the emergence of relational thinking in order to evaluate the hypothesized social process. Our theory is that instantaneous social events that embody modeling, support, and refutation are the precursors of growth in relational thinking in the long run.

1.2. Peer relationships in small group discussions

Small group discussion can be conceptualized as two interweaving networks: an argumentation network in which individuals are expressed as nodes and the connections between individuals' expressed ideas are denoted as ties; and, a social network in which individuals are connected by ties of friendship or status in the classroom social network. Dynamic cognitive and affective ties, involving disagreement, support, power, or friendship, represent multiple dimensions of co-regulation or co-ordination among group members (Vauras, Salonen, & Kinnunen, 2008). Although the idea of a dual-space framework is not new (e.g., Barron, 2003; Olivera & Straus, 2004), the majority of collaborative learning research focuses on one dimension or the other (Van den Bossche, Gijselaers, Segers, & Kirschner, 2006). There is not yet a consensus as to how the cognitive and social facets of collaboration interlace (Ladd, Kochenderfer-Ladd, Visconti, & Ettekal, 2012). Particularly, the role of peer relationships in collaborative learning contexts is still unclear (Tolmie et al., 2010).

Previous studies suggest that progress in cognitive development depends upon positive peer relationships. Students prefer to interact with or seek help from peers who are popular, have more good ideas, or share many characteristics with them. These selection processes thus may influence when and how learning takes place. For example, Azmitia and Montgomery (1993) found that friends are more likely than acquaintances to evaluate, justify, and criticize each other's ideas, which in turn improves their cognitive performance. According to this line of research, peer relationships are a determinant of cognitive development during peer collaboration. However, Tolmie et al. (2010) argued that optimal peer relationships at best establish "sufficient minima to permit further growth as part of productive activity" (p. 188).

Research suggests that social structures can alter individual behavior. A meta-analysis by Roseth, Johnson, and Johnson (2008) concluded that social contexts featuring a cooperative goal structure, as opposed to competitive or individual goal structures, affords greater opportunities for individuals to cultivate positive peer relationships and improves academic achievement. Other studies indicate that an egalitarian social norm can promote positive social behavior, whereas a rigid social dominance hierarchy may foster peer rejection or aggressive behavior (e.g., Chang, 2004; Cohen & Lotan, 1995). Cohen and her colleagues developed an approach in which children were taught that intellectual abilities are multidimensional, such that everyone is gifted in some way, and in which the teacher made a point of publicly recognizing the intellectual contributions of low-status children. Similarly, Boaler (2008) taught students to be respectful of each other and to fairly consider various points of view. These interventions successfully fostered students' interpersonal accountability and positive interdependence and promoted learning, suggesting that micro-level social learning is determined partly by macro-level social structures (Vauras et al., 2008).

The current study therefore assumes that positive peer relationships can have sustaining facilitative effects on cognitive development provided positive social norms such as respect and support are embraced. Consistent with previous research (Faris & Felmlee, 2011), we assume that students who have higher status in the classroom are more likely to take a leadership role by conforming to the collaborative social norms, modeling desired cognitive and social actions, and supporting classmates who conform to norms. Based on these assumptions, this study examined the influence of two important facets of peer relationships – friendship and status in the social network, within an approach to small-group discussion featuring relational equity and critical thinking.

Peer status is a key interpersonal factor that may affect learning. Cohen (1994) defined status as "an agreed-on rank order where it is generally felt to be better to be high than low rank" (p. 23). A person's rank is determined by social evaluation, and does not exist in one single form. According to Lease, Musgrove, and Axelrod (2002), peer status is a multi-dimensional construct. Several dimensions of status have been studied in the social development literature, including but not limited to social preference based on liked-most and liked-least nominations (Newcomb & Bagwell, 1995), social dominance or the relative ability to control material and social resources (Hawley, 1999), perceived popularity (Cillessen & Rose, 2005), and social network centrality (Faris & Felmlee, 2011; Farmer & Rodkin, 1996). In the context of classroom learning, peer status is often associated with academic standing. For example, Cohen and Lotan (1995) measured students' status with 'math and science competence' nominations as well as 'best friend' nominations.

A student's status influences teachers' and classmates' expectations about competence (Berger, Cohen, & Zelditch, 1972). High-status students are expected to have a greater influence on group processes than low-status students. Research has suggested that differential expectations due to status strongly affect students' opportunities to participate in small groups and therefore also affect students' learning gains (Cohen & Lotan, 1995).

The current study considered three dimensions of peer status. The first dimension was *network centrality*, which is defined in this study as an individual's relative position in a friendship network. Individuals who are located in a more centered position in a friendship network tend to be more influential than students in a peripheral location (Faris & Felmlee, 2011). Since socially centered or high-status students have more social connections, they may play an important role in cognitive socialization. However, research has shown that socially centered students may have negative instead of positive influences on each others. For instance, Ellis, Dumas, Mahdy, and Wolfe (2012) found that higher-centrality adolescents interacted with their peers in more dominant and controlling ways than lower-centrality students. One possible reason for the inconsistent findings is that group norms moderate the influence of socially centered students. Socially centered students may be more sensitive to norms and, once adapted to positive group norms, may play an important role in scaffolding relational thinking during dialogic interaction. Thus, network centrality can amplify either positive or negative effects (see Wang & Eccles, 2012), but we assume that only recurrent positive interaction leads to better social and cognitive outcomes.

The second dimension of status was perceived cognitive status. Academic reputation among peers is a significant predictor of self-concept, effort, and average grades after controlling for initial levels of these variables (Gest, Rulison, Davidson, & Welsh, 2008). Chiu and Khoo (2005) found that whether a small group could solve a mathematic problem successfully was influenced by contributions of students perceived to be good in mathematics. We hypothesized that students with a higher perceived cognitive status might generate more relational thinking during small-group discussions and have a greater impact on the cognitive processes during dialogic interaction.

The third dimension of status was peer reputation for quietness. Research shows that quiet students tend to be judged as lower in credibility, attraction, and success than more talkative counterparts (Coplan, Hughes, Bosacki, & Rose-Krasnor, 2011; Daley, McCroskey, & Richmond, 1977). Quiet students are often ignored by teachers and peers (Evans, 2001). In small-group settings where talk is the principal medium of knowledge exchange, students who are quiet may experience difficulty interacting with others because they are perceived to lack ability or knowledge. On the other hand, quiet students may be active thinkers during classroom discussions even though they do not talk much (Townsend, 1998). The current study therefore hypothesized that the influence of quietness was contingent on social context. A small-group activity in which quiet students are respected and invited to participate might facilitate these students' cognitive engagement during discussions.

Friendship is a second important aspect of peer relationships. Early friendship research focusing on the relations between friendship and cognitive outcomes suggested that children learn better when working with friends. Friends can provide a sense of relatedness, belonging, and emotional support, which create a safe and secure context for children to exchange information in a joint problem solving space (Azmitia & Montgomery, 1993), and to be more open to disagreement than nonfriends (Zajac & Hartup, 1997). However, opposite findings were reviewed by Newcomb and Bagwell (1995) and Zajac and Hartup (1997), who commented that friends were more concerned with resolving disagreements and tend to produce more agreement during collaboration than groups composed of non-friends. Balkundi and Harrison (2006) suggested that a high-density friendship network may "bind individual team members into mutual consensus and lack of disagreement" (p. 61) because friends do not want to hurt the relationships that they have devoted time and effort to maintain. Friends may therefore face a dilemma over whether they should strive for better performance or focus on maintaining high affiliation and agreement among group members.

Not until recent years have researchers investigated the mechanisms by which friendship affects learning. Berndt, Laychat, and Park (1990) found that friend dyads' achievement motivation became more similar after having a discussion. Decisions among friends shifted toward an alternative action involving greater achievement motivation when discussions were harmonious and featured reasons that supported the alternative action with greater achievement motivation. Altermatt and Broady (2009) conducted one of the few studies that examined friendship effects by direct observation. A sequential analysis showed that when learners were having trouble solving a difficult puzzle, their help-seeking depended on how their performance was evaluated by friends. This microgenetic study suggested that children not only emulate and internalize friends' behavior but also are influenced by friends' evaluation of their performance. The affective bonds between friends and the inclination to maintain friendships may lead children to align their social goals or values with their friends' (Barry & Wentzel, 2006). Following these process-oriented friendship studies, we hypothesized that children might be biased toward ideas generated by their friends, but additionally that the cognitive effort devoted to supporting their friends may lead to deeper information processing as indicated by the emergence of relational thinking in talk.

1.3. Collaborative reasoning as a context for dialogic interaction

The current study investigated cognitive development during *Collaborative Reasoning* (CR), an open-format, peer-led, discussion forum intended to improve the quality of interaction, to stimulate critical reading and thinking, and to be personally engaging (Chinn et al., 2001). CR provides a sustained collaborative context in which small groups of students try to collaboratively think of good solutions 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. Students take individual positions on the issue, actively present reasons and evidence for their positions, and challenge each other when they disagree. They are not obligated to reach a consensus, but are reminded to be respectful of others' contributions. Students 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. Thus, CR creates a social norm that values different viewpoints and perspective taking, encourages social support, and rewards autonomous attempts to express thinking.

Previous research documents rapid development in aspects of reasoning during Collaborative Reasoning discussions. Several studies involving altogether 100 classes of fourth and fifth graders show that students who participate in as few as four or five CR discussions independently write essays, prompted by a text they have *not* previously read or discussed, that contain more acceptable arguments, counterarguments, rebuttals, uses of text evidence, and uses of formal argument devices than comparable students who have not participated in CR (e.g. Kim, Anderson, Miller, Jeong, & Swim, 2011; Reznitskaya et al., 2001).

These positive outcomes of Collaborative Reasoning provide a warrant for a microgenetic analysis that has the goal of identifying elements of the process that gives birth to learning, because the microgenetic method works best when observations span a period of rapidly changing competence (Chinn, 2006; Siegler, 2006). The first CR study focusing on the moment-by-moment development of relational thinking was conducted by Lin et al. (2012). The study found that students' use of analogy snowballed during and across CR discussions primarily because of the accelerating use of novel analogies, implying that students were acquiring a deeper understanding of analogy.

Although previous studies suggest that dialogic interaction in CR can facilitate aspects of learning and development, the process seems to be influenced by many social factors. For example, Sun, Anderson, Perry, and Lin (revise and resubmit) found that effective leadership moves spontaneously emerged during CR discussions, were more likely to be generated by talkative and socially centered students, and led to better group problem-solving performance. Miller and Anderson (2010) observed five quiet students' discourse patterns across a series of CR discussions, and concluded that quiet students were more involved in a discussion if supported by their peers and teacher.

To summarize, the current study advanced beyond previous research by systematically examining the moment-by-moment and session-by-session development of relational thinking as a function of dialogic interaction and the extent to which interaction during small-group discussions is mediated by students' peer relationships. Specific questions included whether friendship and peer status affect students' interaction patterns and the influence of these social factors on the emergence of relational thinking.

2. Methods

2.1. Participants

Participants were 6 teachers and 120 fourth-grade students (68 girls, 52 boys), who ranged in age from 8 to 12 years ($M = 10.0$, $SD = 0.6$), from six classrooms in four central Illinois public elementary schools. Two classrooms were from a rural school. Four classrooms were from three low- to middle-SES urban schools. Students included 2 Asian Americans, 4 Hispanic Americans, 45 African Americans, and 69 European Americans. Classroom size ranged from 17 to 23 ($M = 20$, $SD = 2.19$).

2.2. Procedure

Teachers participated in a 1-day workshop in which they learned instructional moves to facilitate Collaborative Reasoning discussions and guidelines that they were to encourage the students to follow: (a) talking freely without being nominated by the teacher, (b) not interrupting others, (c) encouraging everyone to participate, (d) listening respectfully to everyone's ideas, (e) considering all sides of an issue, and (f) thinking critically about the ideas and not people.

Research assistants were participant observers in the classrooms on the days discussions were held. Their tasks included making field notes, videotaping, conducting argument stratagem lessons, recommending instructional moves, and providing other support for teachers.

Each class had three discussion groups. The teachers and the onsite research assistants assigned students to groups, each of which was a cross-section of the class in terms of gender, ethnicity, talkativeness, and academic achievement. The size of discussion groups ranged from five to eight students ($M = 6.67$, $SD = .84$).

The groups had 10 CR discussions over a 5-week period. The 10 stories that served as the basis for the discussions were assigned in a fixed order, ranging from easy to difficult (see Appendix). The stories covered a variety of issues including moral dilemmas and child-friendly policy issues. For example, the third story was about two girls discussing whether zoos are good places for animals. The ninth story was about an African American family who lived in the north of the United States. Students had to decide if the family should drive a new gold Cadillac to the South to visit family, during a period when the South was still racially segregated.

Students read each story individually before the ensuing CR discussion. Groups were called one at a time to discuss the story while the other students completed work at their seats. Students were told to collaboratively come up with the best solution to the big question and try to consider both sides of the issue. They did not have to raise their hands to express ideas, but were admonished to show respect for others by listening carefully to what others said and responding to them in a considerate way. Discussions ended with a debriefing session during which the teacher led students in evaluating the strengths and weaknesses of that day's discussion and how to improve the next discussion. On average, discussions were 17 minutes in length. All of the discussions were videotaped and transcribed.

Prior to the third discussion, two students from each group were selected to receive instruction in argument stratagems that do not occur spontaneously among students, with the hope of further evaluating the social propagation mechanism termed *snowballing* (Anderson et al., 2001). However, the instruction did not have significant effects and will not be further discussed in this paper.

2.3. Measures of student and group characteristics

At the beginning of the study, students completed a battery of cognitive assessments, the Figure Classification, Figure Analogy, and Figure Analysis subtests from the Cognitive Abilities Test (Cox, 1969), a wide-range checklist vocabulary test (Anderson & Freebody, 1983), and the reading comprehension subtest from the Metropolitan Achievement Tests (Farr, Prescott, Balow, & Hogan, 1986).

Students' peer relationships were measured with a peer-nomination questionnaire. Friendship was assessed by asking students to nominate at most five best friends in their class. Network centrality was computed as an individual-level centrality measure using social network analysis (SNA in R; Butts, 2008). The concept of centrality represents the importance, prominence, influence, or social status of each individual (called actors) in a network (Wasserman & Faust, 1994). The most prominent or important figure is conceptualized as being located in the central position in the network. Information-centrality is one of the centrality indices; it weights both the direct (my friends) and indirect (my friends' friends, my friends' friends' friends, etc.) friendship relations of a specified child. A preliminary analysis showed that information centrality had stronger associations with outcome variables than alternative centrality indices (indegree, betweenness). Hence, information centrality was selected as the measure of network centrality. For the sake of simplicity, information centrality is hereafter called *network*

Table 1
Relational thinking coding scheme.

Coding category	Definitions	Relational marker	Example	Cohen's kappa
Logical or causal	Premise or conclusion indicators	BECAUSE	That's probably why he got hit by a baseball because he had his eyes closed.	.98
		IF	If she doesn't help Evelyn, then people won't like her very much.	.99
		SO SO THAT	But they still can't make it big enough to seem like home to some of them, and when they give food, they lose their instinct to hunt and look for food, so what you see in the zoo is not really like what you see in the wild.	.97
Analogical or hypothetical	Attempts to compare two domains, or create a hypothetical scenario; assume something that did not happen but could possibly happen in the future; propose an imaginary scenario or alternative to reality	WHAT IF IF YOU WERE	What if you were the goose, how would you feel?	.95
		IS LIKE JUST LIKE THE SAME AS SO AS	How would you like it if someone came and captured you and took you to a far off land; you have to keep the wheel in the hamster's cage, 'cause it has to have its energy, so it won't get paralyzed. That's the same thing with the goose.	.99
Other	Repeating something that has been mentioned; a rhetorical form to catch the audience's attention before a statement; occur without identifiable premises or conclusions	SO	I like animals, and so are a lot of people. He is so smart. I hope so. So, what do you think Kelly should do?	.99
		IF (=whether or not) AS IF	I wonder if his daddy is too busy. It sounds to me as if no one's tryin' to look at things from the Prince's point of view.	.88

centrality. We will refer to students with a high computed index of network centrality as *socially centered* or *high status*.

Perceived cognitive status was measured by asking students to nominate classmates who usually have good ideas. Students' perceived quietness during school lessons was measured by nomination of classmates who are usually quiet in class. All of the measures were standardized by class so that the values were comparable in classes of different sizes. To control for individuals' rate of talk, each student's total turns for speaking per discussion was calculated from the discussion transcripts. A turn for speaking contained interpretable information, but not necessarily a complete sentence.

2.4. Coding discussion transcripts

Three video recordings were damaged during data collection and one discussion transcript was lost. The final corpus was 176 discussions, containing 32,511 turns for speaking. Research assistants transcribed the discussions using Transtool (Kumar & Miller, 2005), recording speech, timestamps, pauses, and comments about nonverbal behavior (gestures, facial expressions) and distracting events (announcements over the public address system). The introduction and debriefing following the discussion, descriptions of nonverbal behavior, and other transcribers' comments were excluded from the analyses. A coding scheme was developed to identify students' relational thinking during the discussions. Another coding scheme was developed to capture social aspects of interaction.

2.4.1. Relational thinking

Relational thinking is operationally defined as using *relational markers* to explicitly convey the connections between idea components. Relational markers function as cohesive devices in discourse that guide participants to search for underlying connections between ideas (Schiffrin, 1987). Relational markers anchored the principal on-line measures of cognitive processes during discussions.

The coding of relational thinking entailed a key-word search for relational markers, defined as words and phrases that can indicate relational thinking, followed by a check of the relational markers in context of use. We began with an exploration of 26 conjunctions, conjunctive phrases, and conjunctive adverbs that could potentially express a higher-order relation. This exploratory search revealed that the great majority of occurrences were BECAUSE, IF, SO, LIKE, SAME, WHAT IF, IF I WERE, and their variations (because, cause, 'cause), which had the corresponding functions of logical reasoning, causal reasoning, analogical reasoning, and hypothetical reasoning. The relational markers identified in the search were then checked in context to eliminate duplicates due to false starts and repetitions, and to eliminate nonlogical and nonrelational uses of markers. Sometimes relational markers occurred in speech fragments with nil propositional content. In these cases, no relational code was assigned. Since causal reasoning is a form of logical reasoning, and analogical reasoning overlapped with hypothetical reasoning to a great extent in this corpus, relational markers that signified these functions were further condensed into logical and analogical/hypothetical reasoning. More details of the relational thinking coding scheme are shown in Table 1. Coding was conducted by one rater. Another rater independently coded 20% of the transcripts (5671 turns for speaking) for a reliability check. Cohen's kappa values of the extent to which the two raters agreed on classifying speaking turns into the following relational thinking categories (logical/causal, analogical/hypothetical, others/nonrelational) are all above .88 (see Table 1 for more details).

2.4.2. Dialogic interaction

Definitions and examples of the dialogic interaction codes are presented in Table 2. One form of interaction was the current speaker's response to the previous speaker, which was classified as *support, refutation*, or *ambivalent*. Another form of interaction was *probing*, which referred to the speaker's attempt to solicit a position, reason, or further elaboration from others. Probing was further categorized into supportive probe, challenging probe, and ambivalent probe. Responses to these probes were coded *response to probe*. Other instances such as asking speakers to repeat, summarizing what previous speakers said, and turn management were coded as *other*.

If speakers talked in order to state their initial positions on the big question or to support their own arguments, this was coded as *self-support*. If the speaker generated a new topic in the discussion, or tried to stop the group from digression, this was coded as *change topic*. Each turn for speaking was allowed to receive multiple codes. Twenty percent of the transcripts were coded by two independent raters to check reliability. Average inter-rater percentage agreement across different categories of dialogic interaction was 97%. Mean Cohen's kappa was .98 (range from .94 to .99).

To examine changes in argumentation networks over time, the third and ninth discussions were selected for turn-by-turn dialogic interaction coding. Microgenetic analysis was conducted with a subset of data because coding dialogue turn by turn is very labor

Table 2
Dialogic interaction coding scheme.

Coding category	Definition	Example	Cohen's kappa
Support	To acknowledge, justify, praise, agreeably elaborate what the previous speaker said, or to offer help based on the previous speaker's request	That's certainly true. I agree with Patrick because that the people might feed them the poison or something, and they try to hurt the animals.	.98
Refutation	To make corrections, suggested alternatives, or posted challenges to the previous speaker	They (animals) could hurt people if they were mad enough. Yeh but they have the fences. I disagree, because look, if they just put the animals that's going to be extinct just put in the zoo, how are we, we ain't going to see other animals.	.95
Ambivalent	To express both support and refutation	I think that I think kinda both because they should go down there 'cause they have a right because white people shouldn't treat them like that and I shouldn't think they should go down there because they could get killed and I wouldn't want my feelings hurt.	.96
Supportive probe	To solicit a position, reason, or other comment from others	Mary, what do you think?	.97
Challenging probe	To request others to provide warrants for their positions	Why do you think so?	.95
Ambivalent probe	To request one student to evaluate another student's statement	What do you think what John said?	.97
Self support	To state own positions to the big question or to support own arguments	I'm a no because um,… when they're out in the forest that they, they have more room-. Oh, it's a no because when they're um in the zoo, they don't have as much room as they do to roam, as they do out in the wild.	.96
Change topic	To stop the group from digression, or to generate a new topic in the discussion	Ok, back to the big question. Should he or should he not?	.99
Other	Asked to repeat sentences, to summarize, to manage turn-taking	Let John talk. Can you repeat that again?	.94

intensive and because previous studies suggest that students display certain recurrent discourse patterns within and across CR discussions (Anderson et al., 2001; Lin et al., 2012). The sampling plan, therefore, was an economical and effective means to model changes in students' argumentative networks throughout the 5-week CR intervention.

After considering several factors that can affect argumentation and group dynamics, the third discussion instead of the first discussion, and the ninth discussion instead of the 10th discussion, were chosen to best represent any progress students made over the series of discussions. First, teachers reshuffled some students to different groups during the first two CR discussions to deal with behavior problems. There were no changes in group membership from the third discussion on. Based on the growth curve model of relational thinking detailed later, there was positive growth in students' use of relational markers over the 10 discussions. However, as Fig. 1 shows, the 10th discussion was below the trend line. This discussion was atypical because the topic was much more difficult; students were supposed to choose among five alternatives for generating electric power, whereas the other discussions involved two options closer to students' experience. Students expressed equal levels of interest and engagement in the third and ninth discussions in the post-intervention group interview, but the 10th discussion was rated lower. In addition, stochastic actor-based modeling requires that the total change between networks being compared must be large enough to make reliable estimates of parameters representing network dynamics.

Both speakers and addressees were identified for each speaking turn based on the content of speech and eye contact observed from the videos. If the whole group talked at the same time, the speaker was recorded as ALL; if the speaker was talking to the whole group, the addressee was recorded as ALL. Turns consisting of polling (e.g., let's go around to state our current position), false starts and other fragments, transcriber descriptions of nonverbal behavior, pauses, and unintelligible turns were removed from the statistical analysis. The inter-rater percentage of agreement in identifying addressees from 20% of the transcript was 94%.

2.5. Data Analysis

2.5.1. Modeling macro-level development

Individual growth curve models were constructed to examine macro-level development, represented in this study as developmental trajectories of relational thinking across the series of 10 CR discussions. The dependent variable was the total number of markers for relational thinking, including logical/causal reasoning and analogical/hypothetical reasoning, generated by each individual in a discussion. Since number of relational markers was an over-dispersed count variable, negative binomial regression models were fit to the data. Although the data set contained a complicated nested

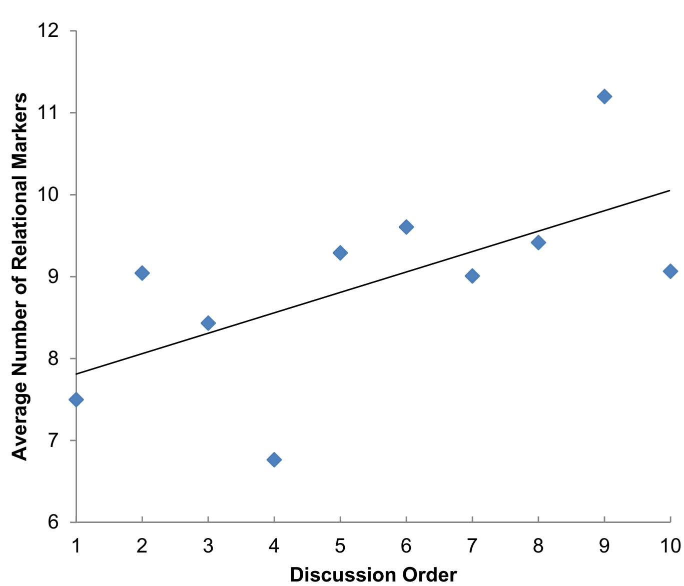

Fig. 1. Growth of relational thinking across 10 Collaborative Reasoning discussions.

structure (discussions nested within students, students nested within groups, groups nested within teachers, teachers nested within schools), preliminary analyses suggest that much of the variance in this study existed at the student level, and neither teacher nor school were confounded with student-level fixed effects. Hence, discussions were nested within students in two-level models. The independent variable of time was represented by discussion order. Reflecting the purpose of this study, three other independent variables to be included were the three peer status variables: network centrality, perceived cognitive status, and perceived quietness. To account for other individual differences, the models controlled for gender, ethnicity, reading comprehension, vocabulary knowledge, and nonverbal reasoning. Total turns for speaking was included to control for talkativeness. Ninety-one values were missing due to student absences. These observations were removed from the analyses.

2.5.2. Modeling micro-level development and temporal antecedents of relational thinking

The micro-level turn-by-turn development of relational thinking, and the dynamics among relational thinking, dialogic interaction, and peer relationships were modeled using Statistical Discourse Analysis (Chiu, 2008; Chiu & Khoo, 2005). SDA is a type of multilevel regression analysis combining sequential analysis and generalized mixed logistic regression analysis for time series data with binary criterion variables. Each discussion was segmented into multiple time periods based on the following conditions: (a) A pause between two speakers lasting for more than 15 seconds occurred, followed by a topic shift; (b) students or the teacher initiated a poll to evaluate everyone's current position; (c) the teacher refocused the group on the big question because the discussion had digressed. Speaking turns were nested within time periods, which were nested within discussions. Preliminary analyses showed that relational thinking did not vary between time periods within discussions, but varied significantly between discussions (estimated variance = 0.16, $SE = .05$, $p < .001$). Hence, we employed two-level random intercept models in which Level 1 was speaking turns and Level 2 was discussion in subsequent models.

In SDA models, the analysis centered on the spontaneous occurrence of cognitive and social events while putting aside the probing events and responses to probe considered in the next section. Focusing on students' spontaneous use of relations and dialogic interaction allowed us to understand the degree to which students consolidated their cognitive and social abilities with minimal scaffolding from others.

Pauses, nonverbal behavior, polling, side talk, choral turns, backchanneling, interjections, failed attempts to gain the floor, fragmentary utterances, simultaneous turns, and inaudible overlapping turns were removed from the SDA analysis because these turns were unlikely to contain relational thinking. Removing these turns enhances the statistical sensitivity of the analysis of temporal influences among the focal events.

To test antecedent factors affecting relational thinking, data were fitted with two-level SDA models in which speaking turns were nested within discussions. Intercepts were allowed to vary across discussions. The dependent variable was the occurrence of relational thinking at the current turn (Lag 0). We hypothesized that the occurrence of relational thinking would be contingent on what the previous speaker said and who the previous speaker was. Hence, the explanatory variables in the model included turn-level and speaker-level variables at the current turn (Lag 0) and one turn before the current turn (Lag −1). The turn-level variables included the previous speaker's standpoint (agree, disagree, ambivalent) and whether the previous statement contained relational thinking (occurrence vs. none). The speaker-level variables included whether the previous speaker was a reciprocated friend of the current speaker, and the current speaker's and the previous speaker's gender, ethnicity, and peer status (network centrality, perceived cognitive status, perceived quietness).

2.5.3. Modeling dynamic argumentation networks

A fine-grained analysis of network dynamics using a social network approach called Stochastic Actor-Based modeling (SAB) for network dynamics (Snijders, van de Bunt, & Steglich, 2010) in RSiena (Simulation Investigation for Empirical Network Analysis, version 1.1–251) was conducted to investigate changes in features of discussion dynamics. This model assumes that social networks are subject to gradual and continuous change (continuous time assumption). Network changes are in part determined probabilistically by the network's past state (Markov process assumption). For example, a new reciprocal tie is more likely to be formed between a pair of actors who are already linked by a unidirectional tie than between a pair of actors who are not connected. At any given point in time, only one actor can make a change on one social tie (sequential change assumption). Actors in the network can make choices about when and how they would like to change a tie (actor-based assumption). The model assumes that every social actor can choose whom he or she wants to form/remove a connection with and when the connection will be formed/removed. Hence, the likelihood of change of a social tie may be a function of an actor's position in the social network (e.g., network centrality) as well as the attributes of the actors or receivers (e.g., gender, ethnicity).

A SAB model is a suitable approach to model dynamic changes of argumentation networks in Collaborative Reasoning discussions. In CR discussions, support and refutation ties occur momentarily, and these moment-by-moment changes add up to large differences between argumentation networks (continuous change assumption). The discourse patterns of CR discussions at any point can be expected to influence the discourse patterns at a later time (Markov assumption). A student is an active speaker who creates an interaction tie in the form of support, refutation, or other rhetorical function (Table 2). Speaking is voluntary so that students can decide when they want to jump into the discussion and whether they want to respond to a probing question from their peers or the teacher (actor-based assumption). Students are encouraged to speak one at a time so that every idea can be heard, and ideas can be linked and mutually influence each other (sequential change assumption). Changes in discourse patterns can be gauged by repeatedly observing the actors at discrete times while taking into account the temporal dependence of the repeated observations.

The data involved 36 argumentation networks constructed from the 18 groups' third and ninth discussions. These networks were complete networks and had relatively few changes in memberships (only 14 missing values existed in the data set due to student absence). A multi-group option (Ripley, Snijders, Boda, Vörös, & Preciado, 2014) was used to bind the 18 pairs of small individual networks into a large multi-group network. The multi-group option was important for the current study because the size of each argumentation network was too small (i.e., five to eight actors) to be analyzed separately. The merged multi-group network contained 120 actors and two observation moments (the third and ninth discussions), which provided adequate statistical power to ascertain the general patterns of network dynamics from the SAB models. Our data do not satisfy the multi-group assumption that all individual networks evolve in the same way. Thus, the model parameters obtained in this study represent the predominant direction of network change and catch the factors that typically influence network change; however, since not every network evolved in just the same way, there were networks that deviated from overall trends. Possibly the multi-group assumption was not met because the number of individuals in each network was small and the data had a complex nesting structure (individuals were nested within groups, which were nested within classrooms).

Every argumentation network was subdivided into a support and a refutation network. In the support network, a tie was formed when a student supported a previous speaker's contribution or expressed a supportive probe. In the refutation network, a tie was formed when a student initiated a response that was coded as refutation or a challenging probe. The number of ties generated between each pair of speakers and addressees was calculated. The initial argumentation networks were valued networks in which the values were counts of the number of ties. These valued networks were transformed into binary networks (1 = at least one supportive/refutational tie was formed between a pair of actors during a discussion; 0 = no tie was form between a pair of actors during a discussion) because only binary data can be analyzed in RSiena (Ripley et al., 2014). For adequate statistical power, the total number of changes in argumentation networks between two observation points should be large enough to model network dynamics. At the same time, there should be enough stability to fulfill the assumption of gradual change between observations. The Hamming distance index measuring the total number of changes (228 for the support network; 238 for the refutation network), and the Jaccard index measuring network stability (.361 for the support network; .307 for the refutation network) indicated adequate amounts of change and stability as suggested by Snijders et al. (2010).

SAB models entail a rate function and an objective function. The rate function represents expected number of changes that will be made by an actor in a given time period, which indicates the rate at which the actor gets an opportunity to change interactions with peers. For example a rate function of five means that on average, a group member has five opportunities to make changes in his or her interaction with other group members during a time period. The objective function estimates the odds that the network will undergo certain types of change between two discrete time points, in the current analysis between Discussions 3 and 9. SAB implements the continuous-time Markov process by repeatedly imputing possible network change trajectories for the unobserved periods between observed moments. SAB assumes that the state of a network at time t is influenced by the network's structure at time $t - 1$. Structural effects on change must be controlled before considering the attributes of the students and their peer relationships. The stochastic actor-based models included three structural parameters representing the overall ways students interact with other group members. *Density, or outdegree,* measures the overall tendency of students to generate supportive or refutational statements. *Reciprocity* measures the tendency of students to reciprocally support or challenge each other. *Transitive triplets* measure the tendency of students to speak to someone whose utterances are indirectly related to theirs.

Beyond structural effects, network change may also be influenced by actor attributes, as well as the attributes formed by relations between pairs of actors, hereafter called dyadic attributes. The actor attributes that were explored in this analysis included the speakers' gender, ethnicity, peer status (network centrality, perceived cognitive status, perceived quietness), and cognitive performance measured by counts of relational markers averaged across the 10 discussions.

In this study, dyadic attributes were relations between pairs of students in a group involving friendship nomination and good-idea nomination. That is, each dyadic value encoded whether or not a given student nominated another student as a friend or as having good ideas. We were especially interested to know whether reciprocated friendship (two students nominate each other as friends) and mutual respect (two students nominate each other as having good ideas) would have a detectable influence on argumentation networks.

Missing data due to student absence were handled through the Siena missing data method (Huisman & Steglich, 2008). Score-type tests (Schweinberger, 2011) were used for backward model selection. The convergence of the RSiena algorithm was checked using t-ratios. Convergence was judged adequate when all of the t-ratios were less than 0.15. Nonsignificant effects were removed from models to avoid multicollinearity issues (Ripley et al., 2014).

3. Results

The corpus of 176 Collaborative Reasoning discussions contained 29,019 student turns for speaking, after removing introduction, debriefing, notations of pauses, speech fragments, unintelligible turns, transcriber comments, and teacher turns. Students generated 9924 relational markers in 6869 turns. Eighty-nine percent ($N = 8823$) of the relational markers were coded as logical, and 11% ($N = 1{,}101$) were coded as analogical/hypothetical. On average, students collectively generated 56.33 relational markers per discussion, while teachers generated 3.95 relational markers. Fig. 1 shows that students generated more relational markers in later discussions.

3.1. Macro-level growth of relational thinking

The growth curve models examined the discussion-by-discussion development of relational thinking (Table 3), which we will refer to as macro-level growth. A likelihood ratio chi-square test comparing the model without random intercept and slope effects with the unconditional growth curve model (UGM) estimating the random effects of individuals' initial relational thinking status and the rate of change in relational thinking was statistically significant ($\chi^2_{(3)} = 516.78$, $p < .001$). Another likelihood ratio test comparing the unconditional means model (UMM) (with random intercepts only) with the UGM model was also significant ($\chi^2_{(1)} = 19.94$, $p < .001$). These findings indicate that students' initial relational thinking status and rate of change varied significantly between individuals. A random intercept and slope model in which Level 1 was discussion and Level 2 was student was therefore better for modeling repeated measures of counts of relational thinking than models without random effects or only random intercepts.

The UGM model examined the rate of change in relational thinking. Discussion order had a significant effect ($\beta = 0.04$, $SE = 0.01$, $p < .01$). Fig. 1 shows the upward linear trend across discussions in average numbers of relational markers. A Box–Tidwell test for nonlinearity further confirmed the linear growth of relational thinking across discussions (score statistic = –.06, $p = .94$).

Model 3 controlled for student attributes, including gender, ethnicity, reading comprehension, vocabulary knowledge, and nonverbal reasoning. While reading comprehension ($\beta = 0.006$, $SE = 0.002$, $p < .01$) and ethnicity ($\beta = 0.26$, $SE = 0.14$, $p < .05$) significantly predicted students' relational thinking, the discussion order effect remained significant ($\beta = 0.04$, $SE = 0.01$, $p < .01$).

Model 4 through Model 6 separately examined three peer status effects on relational thinking. Network centrality ($\beta = 7.97$, $SE = 2.61$, $p < .01$), perceived cognitive status ($\beta = 0.17$, $SE = 0.08$, $p < .05$), and perceived quietness ($\beta = -0.37$, $SE = 0.06$, $p < .001$) all showed positive associations with relational thinking after controlling for gender, ethnicity, verbal and nonverbal cognitive ability. More relational markers were generated by a student if the student had higher network centrality, higher perceived cognitive status, or lower perceived quietness.

Model 7 assessed the relative importance of the three peer status factors. Network centrality and perceived quietness remained significant ($\beta = 5.42$, $SE = 2.44$, $p < .05$, $\beta = -0.35$, $SE = 0.06$, $p < .001$, respectively), but the perceived cognitive status became nonsignificant when considered jointly with the other two peer status measures. This might be because much of the variance that could be explained by perceived cognitive competence had been explained by students' actual measured competence, as there were

Table 3
Growth curve models of relational thinking over 10 discussions.

	UMM	UGM	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Fixed effects								
Intercept	1.97*** (0.07)	1.72*** (0.09)	2.13** (0.70)	1.15 (0.75)	2.78*** (0.72)	2.36*** (0.62)	1.82** (0.70)	2.17** (0.71)
Gender (1 = female, 0 = male)			0.12 (0.13)	0.08 (0.12)	0.03 (0.13)	0.16 (0.11)	0.07 (0.11)	0.06 (0.12)
Ethnicity (1 = White, 0 = Other)			0.26* (0.14)	0.20 (0.13)	0.18 (0.14)	0.09 (0.12)	0.08 (0.12)	0.03 (0.12)
Reading Comprehension			0.006** (0.002)	0.006** (0.002)	0.004* (0.002)	0.006** (0.002)	0.005* (0.002)	0.004* (0.002)
Vocabulary			0.12 (0.11)	0.11 (.10)	0.04 (0.11)	0.15 (0.09)	0.09 (0.09)	0.07 (0.10)
Nonverbal reasoning			−0.005 (0.004)	−0.004 (.004)	−0.01 (0.004)	−0.007 (0.004)	−0.007 (0.004)	−0.007 (0.004)
Network centrality				7.97** (2.61)			5.42* (2.44)	2.69 (2.53)
Perceived cognitive status					0.17* (0.08)		0.11 (0.07)	0.14* (0.07)
Perceived quietness						−0.37*** (0.06)	−0.35*** (0.06)	−0.31*** (0.06)
Total turns for speaking								0.001*** (0.000)
Rate of change								
Discussion order		0.04*** (0.01)	0.04** (0.01)	0.04*** (0.01)	0.04*** (0.01)	0.04*** (0.01)	0.04*** (0.01)	0.03** (0.01)
Discussion order × discussion order								
Random effects								
Variance of intercept	0.47 (0.07)	0.77 (0.14)	0.70 (0.13)	0.62 (0.11)	0.72 (0.13)	0.67 (0.13)	0.63 (0.12)	0.60 (0.12)
Variance of slope		0.005 (0.002)	0.005 (0.001)	0.005 (0.001)	0.005 (0.001)	0.005 (0.001)	0.005 (0.001)	0.005 (0.001)
Covariance		−0.04 (0.02)	−0.04 (0.01)	−0.03 (0.01)	−0.04 (0.01)	−0.04 (0.02)	−0.04 (0.01)	−0.04 (0.01)
Fit statistics								
AIC	6685	6633	6631	6624	6630	6601	6597	6571

Note: UMM, unconditional means model; UGM, unconditional growth model.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

significant correlations between perceived cognitive status and reading comprehension, vocabulary, and nonverbal reasoning ($r = .46$, .41, .35, respectively).

To rule out possible confounding effects of amount of talk, each student's total turns for speaking during each of the discussions was included in Model 8. The network centrality effect became nonsignificant, while cognitive status became marginally significant. Perceived quietness remained a very significant predictor of counts of relational thinking ($\beta = -0.31$, $SE = .06$, $p < .001$). One possible explanation for the nonsignificant network centrality effect was that the influence of network centrality is mediated by turns for speaking. To test this mediation hypothesis, total turns for speaking was predicted by network centrality while controlling for the other student characteristics. The effect of network centrality was highly significant ($\beta = 11.21$, $SE = 1.17$, $p < .001$), suggesting that high status, or socially centered, students had more opportunities to take the floor during discussions and therefore generated more relational thinking. The effect of perceived cognitive status remained significant but only marginally ($\beta = 0.14$, $SE = 0.07$, $p < .05$). Quietness nominations remained very significant even after total turns for speaking were taken into account ($\beta = -0.31$, $SE = 0.06$, $p < .001$). This suggests that perceived quietness is more than a measure of the students' tendency not to talk very much.

3.2. Micro-level development of relational thinking and its temporal antecedents

This section describes analyses of the micro-level development of relational thinking, meaning development speaking turn-by-speaking turn, as a function of spontaneous support and refutation, and how students' social and cognitive attributes facilitated or inhibited students' spontaneous relational thinking. After removing pauses, nonverbal behavior, and other miscellaneous turns described in Section 2, the data set contained 3958 turns, of which 22% ($N = 871$) expressed agreement, 30% ($N = 1144$) expressed disagreement, 1% ($N = 33$) were ambivalent, and 47% ($N = 1910$) were probes, self support, topic change, and others. Students produced 1306 turns containing relational thinking. Other discussion-level descriptive statistics are shown in Table 4. Confirmational and refutational relations are utterances containing relational thinking used to argue for or against the viewpoint expressed by the previous speaker. The two types of utterances were analyzed separately because the social network analyses described below showed that support and refutation were associated with different individual attributes. Nonsignificant variables were removed to maintain parsimony and improve model fit.

In the confirmational relations model summarized in Table 5, the occurrence of conformational relational thinking at the current turn, notated Lag 0, was significantly predicted by relational thinking at the previous turn, notated Lag −1 ($\beta = 0.61$, $SE = 0.15$, $p < .001$), suggesting that once spontaneous relational thinking occurred, a confirmational relation was more likely in the following turn. A confirmational relation was also triggered by agreement ($\beta = 0.60$, $SE = 0.13$, $p < .001$) but not disagreement or ambivalent statements. The significant agreement effect on the occurrence of confirmational relational thinking indicates that if the previous speaker (Lag −1) expressed agreement with the child who spoke two turns earlier (Lag 2), the current speaker (Lag 0) was more likely to support the previous speaker with a statement that contained relational thinking. The significant reciprocated friendship effect ($\beta = 0.54$, $SE = 0.17$, $p < .001$) suggests that when the previous speaker was the current speaker's reciprocated friend, there was a greater tendency for the current speaker to produce a confirmational relation. Gender, ethnicity, network centrality, perceived cognitive

Table 4
Means and SDs of students' rhetorical moves per discussion.

Rhetorical move	*Mean*	*SD*	MIN	MAX
Spontaneous agreement	24.19	15.50	4	61
Spontaneous disagreement	31.78	25.10	1	122
Spontaneous ambivalent turn	0.92	1.25	1	5
Confirmational relation	8.33	6.50	0	29
Refutational relation	10.14	6.19	0	24
Supportive probe	8.94	7.90	0	31
Challenging probe	7.33	8.11	0	28
Self support	10.22	7.21	0	30
Change topic	5.06	4.90	0	29
Response to probe	17.00	10.26	0	44

Table 5
SDA models of relational thinking.

Effect	Estimate	*SE*	*t*	CI
Confirmational relation				
Fixed effects				
Intercept	−3.00	0.15	−19.58***	[−3.30,−2.69]
Relational thinking (Lag −1)	0.61	0.13	4.74***	[0.36,0.86]
Agreement (Lag −1)	0.60	0.13	4.47***	[0.33,0.86]
Reciprocated friend (Lag −1)	0.54	0.17	3.28***	[0.22,0.87]
Random effect				
Variance of intercept	0.49	0.16		
Refutational relation				
Fixed effects				
Intercept	−1.69	0.39	−4.29***	[−2.48−0.91]
Relational thinking (Lag −1)	0.39	0.12	3.30***	[0.16,−0.62]
Disagreement (Lag −1)	0.60	0.12	5.22***	[0.38,0.83]
Reciprocated friend (Lag −1)	−0.27	0.18	−1.49	[−0.62,0.09]
Network centrality (Lag 0)	6.01	3.09	1.95*	[−0.05,12.07]
Network centrality (Lag −1)	−13.84	3.13	−4.41***	[−20.00,−7.68]
Random effect				
Variance of intercept	0.08	0.05		

Note: Gender, ethnicity, perceived cognitive status, perceived quietness at Lag 0 and Lag −1, and ambivalent turn at Lag −1 did not predict confirmational relation or refutational relation at the current turn. These variables were removed from both models to maintain parsimony and improve model fit.
CI, confidence interval.
+ $0.05 < p < 0.10$.
* $p < .05$.
*** $p < .001$.

status, and perceived quietness were not significant at the current turn or the previous turn.

As shown in Table 5, a refutational relation at Lag 0 was triggered by another relational statement ($\beta = 0.39$, $SE = 0.12$, $p < .001$) or by disagreement ($\beta = 0.60$, $SE = 0.12$, $p < 0.001$) at Lag −1. The significant effect of network centrality at the current turn suggests that socially centered students tended to generate more refutational relations ($\beta = 6.01$, $SE = 3.09$, $p = .05$). Network centrality was significant at Lag −1 ($\beta = -13.84$, $SE = 3.13$, $p < .001$). If the previous speaker had lower network centrality, the current speaker was more likely to refute with relational thinking. Whether a speaker had higher perceived cognitive status or was perceived as quiet, either at the current turn or the previous turn, did not predict the use of refutational relations at the current turn. The current and previous speakers' gender and ethnicity did not predict the use of a refutational relation at the current turn.

Sometimes a speaker repeats the same idea in consecutive turns. Leaving these duplicated turns in the analysis might bias the results. After removing duplicated turns, a confirmational relation model and a refutational relation model fitted to the reduced data set showed that all of the previous findings hold.

Both the confirmational relation model and the refutational relation model showed a significant effect of relational thinking at Lag −1, indicating that relational thinking was more likely to occur following relational thinking in the previous turn. In addition, even when the relations generated by the same speaker were removed, the effect of relational thinking at Lag −1 was highly significant in the SDA models. Therefore, we could reject the idea that increases in relational thinking represented repeated contributions by the same speakers.

3.3. Dynamic changes in dialogic interaction

The previous section documented that spontaneous relational thinking was associated with students' agreement or disagreement with others, and was directly influenced by certain forms of peer relationships. However, peer relationships may as well have an additional indirect influence on relational thinking via influence on changes in the characteristics of dialogic interaction. This section therefore explored how support and refutation generated by students during discussions changed from the third to the ninth discussion as a function of pre-existing peer relationships. Argument networks for the 36 discussions, including both spontaneous and prompted argumentation ties, contained 1275 supports, 1326 refutations, 79 ambivalent turns, 334 supportive probes, 278 challenging probes, 417 self-supports, 4 topic changes, and 433 responses to probes, and 217 miscellaneous statements.

According to the Stochastic Actor-Based model of the *support network*, the rate of change in supportive ties from the third to the ninth discussions was greater than 0 for every discussion group, ranging from 1.18 to 13.53. Thus, depending on which group an actor belonged to, s/he would have at least 1 and at most 14 opportunities to change his/her supportive ties between the two discussions. As shown in Table 6, the three structural variables all significantly predicted the probability of change in supportive ties. The negative density effect ($\beta = -0.46$, $SE = 0.18$, $p < .01$) indicates that the tendency for group members to provide support to others became a more selective process, as opposed to a random event, which may

Table 6
Stochastic actor-based models of changes in supportive and refutational ties.

Parameter	Support network			Refutation network		
	Estimate	*SE*	*t*	Estimate	*SE*	*t*
Rate Function						
Group 1	13.53	7.79		3.06	1.35	
Group 2	5.26	2.05		4.64	1.77	
Group 3	5.66	3.25		10.89	6.74	
Group 4	6.56	3.03		55.52	47.67	
Group 5	9.00	3.58		4.02	1.48	
Group 6	8.83	3.73		42.00	34.37	
Group 7	7.06	3.47		37.72	26.87	
Group 8	2.14	1.01		11.05	6.97	
Group 9	1.86	1.05		1.88	1.02	
Group 10	2.33	0.85		5.27	2.26	
Group 11	4.83	1.26		5.06	1.67	
Group 12	4.99	1.61		4.79	1.86	
Group 13	1.19	0.74		4.36	2.53	
Group 14	6.47	3.48		1.78	0.66	
Group 15	3.39	1.47		4.71	2.15	
Group 16	4.53	2.28		3.94	1.63	
Group 17	7.29	3.84		33.28	25.99	
Group 18	2.87	1.33		2.21	1.17	
Objective function						
Structural effects						
Density	−0.45	0.18	−2.53**	−0.81	0.16	−5.04**
Reciprocity	0.81	0.21	3.90**	1.09	0.21	5.19**
Transitive triplet	0.12	0.05	2.48**	0.12	0.05	2.50**
Dyadic attributes						
Friendship nomination	0.45	0.19	2.35**	−0.02	0.17	−0.10
Good-idea nomination	0.29	0.16	1.80	−0.31	0.16	−1.92
Speaker attributes						
Perceived quietness	−0.01	0.02	−0.59	−0.35	0.09	−4.04**
Network centrality	0.36	0.15	2.37**	7.92	3.30	2.40**
Relational thinking	0.05	0.02	2.55**	0.02	0.01	1.57
Addressee attributes						
Perceived quietness	0.03	0.02	1.76	−0.12	0.08	−1.55
Network centrality	0.25	0.14	1.71	6.06	3.25	1.87
Relational thinking	0.01	0.02	0.81	0.01	0.01	0.87

Note: The table reports one set of estimated coefficients of the rate functions and structural variables because the estimates were fairly stable regardless of whether the model included the speaker attributes or addressee attributes.
A significant speaker attribute effect means that children with the specific attribute are likely to generate support or refutation; a significant addressee attribute effect refers to the type of children who are likely to receive support or refutation from others.
* $p < .05$.
** $p < .01$.

have depended on such factors as previous experience talking with a certain student and who the student was. The positive reciprocity effect ($\beta = 0.81$, $SE = 0.21$, $p < .01$) and the positive transitive triplet effect ($\beta = 0.12$, $SE = 0.05$, $p < .01$) indicate that students generated increasingly more reciprocated and transitive supportive talk with members of their group both within discussions and over the series of discussions.

After controlling for the structural effects (density, reciprocity, transitivity), the model showed a significant and positive effect of friendship ($\beta = 0.45$, $SE = 0.19$, $p < .01$). This dyadic effect suggests that students became more likely to provide support to others in the group whom they nominated as friends. The effect of reciprocated friendship on change in supportive ties was also examined but was not significant. Good-idea nomination did not predict change in supportive ties.

A significant speaker attribute effect means that students with the attribute are likely to *provide* support or refutation, while a significant addressee attribute effect means that students with this attribute are likely to *receive* support or refutation from others. Among the speaker attributes, speakers with high network centrality ($\beta = 0.36$, $SE = 0.15$, $p < .01$) and speakers who generated more relational thinking throughout discussions ($\beta = 0.05$, $SE = 0.02$, $p < .01$) tended to provide more support to others. None of the addressees' attributes predicted changes in the support network.

The analysis of refutation network indicated that the rate of change in refutational ties ranged from 1.78 to 55.52. In other words, depending on which group a student belonged to, the student would have at least 1 and at most 56 opportunities to change his/her refutational ties between the third and the ninth discussion. Similar to the support network, the density, reciprocity, and transitive triplet effects were significant (Table 6). Whether a pair of students were friends, either reciprocated or non-reciprocated, did not predict changes in speaker's refutational ties. Between the third and the ninth discussion, speakers perceived as quiet became less likely to refute others ($\beta = -0.35$, $SE = 0.09$, $p < .01$), whereas speakers with high network centrality refuted others more often ($\beta = 7.92$, $SE = 3.30$, $p < .01$). Similar to the analysis of support network, none of the addressees' attributes predicted changes in the refutation network.

Gender, ethnicity, and perceived cognitive status were not significant in either the support or refutation analysis and were therefore removed from the models. Although good-idea nomination did not significantly predict change in the support network, this dyadic attribute was close to significant in predicting changes in the refutation network and was retained in both models to facilitate comparison.

Below is an excerpt from the ninth discussion showing a typical exchange between socially centered students and their peers. Anne, one socially centered student, asked Becky to elaborate what she thought about the big question. After Becky responded to Anne's supportive probe, Jim, another socially centered student, picked up on what Becky said and further elaborated the idea with relational thinking. This excerpt illustrates that socially centered students often supported other students when their statements contained an unclear position or a poorly-elaborated reason.

Becky I think that, um, they should go down south.

Anne Why do you think that?

Becky Because it is a free country and um it doesn't really matter what color you are because we are all the same we're just different colors.

Jim Becky, you said that we're all the same and I agree with you because it doesn't really matter what color you are because um what if everybody in the world was black then there'd be like no signs that says black, I mean, there'd be no signs that said white only be all black people and if there's all white people then there'd be no black signs that says no black people…we're all the same inside we're different inside but we're all the same, we're all human beings.

4. Discussion

The major conclusion of this study is that the micro-level and macro-level development of relational thinking is contingent upon those with whom students interact, patterns of dialogic interaction, and individual characteristics. Peer relationships, particularly friendship and status in the classroom social network, had a direct influence on patterns of dialogic interaction, which in turn shaped students' relational thinking. While there is a general consensus that social factors impact learning and development in small-group settings (Barron, 2003; Olivera & Straus, 2004), this is one of the few studies that systematically examines the underlying mechanisms by which peer relationships facilitate or hinder group processes thereby impact individual cognitive development.

The following sections summarize and attempt to explain the findings about micro- and macro-development of relational thinking during Collaborative Reasoning discussions; changes over time in dialogic interaction and relational thinking; and the role of peer status, friendship, and other student characteristics in dialogic interaction and the development of relational thinking.

4.1. Macro- and micro-development of relational thinking

The individual growth curve models showed students enacted relational thinking at an increasing rate across 10 Collaborative Reasoning discussions. The macro-development of relational thinking was not simply due to an increase in the amount of talk, since the slope coefficient representing rate of growth in relational thinking remained significant after controlling for total turns for speaking. Within discussions, relational thinking spread turn-by-turn to different students (see Section 3.2 and Table 5). Thus, momentary changes are accumulated over time and become more crystallized within individuals. We conclude in common with historic figures such as Vygotsky (1978, p. 65), as well as contemporary scholars (Siegler, 2005; Thelen, as described in Spencer et al., 2006), that integrating multiple time scales is indispensable for a full understanding of development.

4.2. Dynamic changes in dialogic interaction and relational thinking

Not only did students generate more relational thinking over time, students became more reciprocally and transitively connected to each other via support and refutation within and across the series of discussions, as indicated in the Stochastic Actor-Based models (SAB) summarized in Table 6. The dynamic changes in dialogic interaction and relational thinking was further supported by the Statistical Discourse Analyses (SDA) presented in Table 5, which showed that when a student observed peers' supportive or refutational talk, whether the support or refutation was directed to this student or someone else, there was an increased likelihood that the student would follow with relational thinking.

Students whose rate of relational thinking was high tended to provide more support to others. These findings indicate that through social support, students co-develop ideas in more depth. Having opinions supported by peers prompts both the listeners and the speakers to continue contributing to the discussion and trying to improve their arguments. Diverse viewpoints among a group of students stimulated consideration of more alternatives and more development of counterarguments.

4.3. Peer status, friendship, and temporal antecedents of relational thinking

A major contribution of the current study was the converging findings that peer status and friendship were associated with positive dialogic interaction and growth in relational thinking during collaborative discussions. Counts of relational thinking were highly associated with students' network centrality, as represented by information centrality, a measure that weights indirect connections as well as direct connections with peers. Students with higher network centrality were more active and cogent discussants. These socially centered students were more talkative and generated more relational thinking during discussions (Table 3, Model 4). Throughout discussions, socially centered students provided more support and refutation to other group members (Table 6).

These results indicate that students at the center of the classroom friendship network play an influential role in creating a stimulating and friendly discussion environment in which everyone has the opportunity to make contributions. This is, perhaps, inconsistent with previous research suggesting that socially centered students are more aggressive and dominant during peer interaction (e.g., Ellis et al., 2012; Rodkin, Farmer, Pearl, & van Acker, 2006). Based on Expectation States Theory (Berger et al., 1972), we conjecture that socially centered students were expected by their peers to positively influence the group process. Such expectations led socially centered students to readily accept the prosocial norms of Collaborative Reasoning and shape their discourse moves in a way that fostered a positive environment for discussion.

Socially centered students provided more support and refutation to their peers, but did not receive more support or refutation from them. This conclusion follows from the significant network centrality effect as a speaker attribute but not an addressee attribute. This suggests that while support and refutation were more likely to be generated by socially centered students over time, these moves were not directed toward students of any particular social status. The study does not allow us to evaluate the possibility that providing support and refutation to others may enhance students' network centrality status. Future studies should include social network measures following a series of discussions, as well as beforehand, to evaluate whether students' status among peers changes depending on their performance during a series of discussions.

In contrast to high status students, low status, or peripheral, students were more likely to receive refutational relational thinking from other group members (Table 5), probably because the statements of low-status students often lacked relational thinking. However, we cannot rule out the possibility that peripheral students are frequently challenged because they are less accepted by their peers who have lower expectations for them. Further research is needed to determine the reasons behind the high rate of refutation directed toward low-status students.

The study showed that students nominated as quiet by their classmates generated less relational thinking than other students (Table 3). However, this finding cannot be simply attributed to these students talking less, because perceived quietness remained highly significant after controlling for total turns for speaking. Apparently, perceived quietness is a more subtle social construct than just a measure of tendency not to talk very much. Following other investigators (e.g. Coplan et al., 2011; Daley et al., 1977), our conjecture is that perceived quietness may be associated with the amount of attention and support that students judged to be quiet receive from their peers and teachers.

The micro-level analyses further suggest that students perceived to be quiet became less likely to disagree with others (Table 6) over the discussions. However, when they did disagree, their likelihood of generating refutational relations was not statistically different from more talkative students, as suggested by the nonsignificant quietness effect in the SDA model (Section 3.2). This supports Townsend's (1998) observation that being quiet is not always equivalent to being less engaged in class. Once quiet students are provided a friendly environment to express their thoughts, these students may be more likely to break the cycle of self-fulfilling prophecy, and become more active discussion participants. Future studies are needed to further examine the learning trajectories of quiet students.

Good-idea nomination reflects perceived task-competence and is the only social measure that correlated with the measures of cognitive ability in the present study. Unlike students with high network centrality, students nominated by their peers as having good ideas did not generate more spontaneous confirmational or refutational relations to agree or disagree with the previous speaker (Section 3.2). The individual growth curve models also show that perceived cognitive status was less predictive of relational thinking than perceived quietness and network centrality. Perhaps this is because perceived cognitive status is more variable compared with perceived quietness and network centrality, oscillating momentarily based on group members' behavioral exchange patterns (Correll & Ridgeway, 2003). That is, students' cognitive status may be judged higher if their ideas are supported or meaningfully challenged by others as opposed to being rudely contradicted (Chiu, 2008). Alternatively, the unstable effect of perceive cognitive status might be due to the fact that some of the variance had been explained by the measures of reading comprehension, vocabulary, and spatial reasoning, although reading comprehension was the only measure that marginally predicted relational thinking. Altogether, these findings suggest that cognitive competence, whether judged by peers or assessed with ability tests, is not a major factor in whether students experience growth in relational thinking during collaborative discussions.

In addition to peer status effects, friendship was found to affect dialogic interaction and relational thinking in the current study. The SAB models demonstrated that students became more likely over time to support those whom they thought of as friends (Table 6). This might be because students perceived their beliefs to be in line with their friends' beliefs, or because the greater level of intimacy and affiliation led students to think in the same ways as their friends. The SDA models further showed that in adjacent turns for speaking, students were more likely to support their reciprocated friends with confirmational relational thinking (Table 5) than they were to support acquaintances. It seems that speaking up to support friends' arguments provided opportunities for students to improve their relational thinking.

We found it somewhat surprising that friends were not more likely to disagree with friends than to disagree with acquaintances, as suggested by two nonsignificant friendship effects: the reciprocated friendship effect in the refutational relation model in Table 5, and the unreciprocated friendship effect (measured by the dyadic attribute of one-way or mutual friendship nomination) in the refutation network model in Table 6. This might be because refutation requires a stronger friendship tie or a more connected friendship network. In the current study, the number of reciprocated friends in a group was low. Students who had strong friendship ties were likely to be assigned to different groups because of heterogeneous grouping. An alternative explanation is that friends might feel more comfortable in providing support or refutation to each other in a more intimate setting. The presence of nonfriends in a heterogeneous small group might change interaction patterns, leading to a greater need for positive evaluation from friends or perhaps more reluctance to oppose friends in front of others. Future studies are needed to understand the factors that disincline students from opposing their friends during small-group discussions, and to develop a more open environment that can promote refutational relational thinking among friends.

Teachers often struggle with how to form small groups to promote more effective small group activities (Gillies & Boyle, 2010). However, research on group composition has mainly focused on group size, ability grouping, or gender composition (Webb & Palincsar, 1996), while the impact of peer relationships, which makes good sense to school teachers (Gillies & Boyle, 2010), has not been examined in depth. Understanding the role of peer relationships thus can provide insights for educational practitioners, enabling them to thoughtfully consider peer relationships while implementing small group activities.

4.4. Limitations of the current study

The current study has several limitations. First of all, peer relationships were measured only once before the 5-week Collaborative Reasoning intervention. Thus, friendship and peer status influences were necessarily assumed to be time-invariant. While many researchers (e.g., Brendgen, Vitaro, Bukowski, Doyle, & Markiewicz, 2001) assume that friendship and peer status are relatively stable constructs that would not change much in a 5-week time span, given that CR entails an intensive social and cognitive process, group members might become closer to or alienated from each other during the series of discussions. We conjecture that typically CR might reshape peer relationships in a more positive direction because CR norms advocate mutual respect and support and students generally seem to try to follow these norms.

In the individual growth curve model, there was substantial variance of intercept and variance of slope that remained unexplained, even though all of the available social and cognitive measures were examined. A needed next step is to discover other potential time-varying factors that might account for the unexplained variance.

Due to an inherent requirement of the SAB modeling technique, the support and refutation networks were transformed from multi-valued networks to binary networks. Some information was lost during the transformation and subtle effects may have been missed.

The growth of relational thinking was indexed by explicit relational markers in this study. Relational thinking might occur without explicit relational markers. It is likely that in many cases relational thinking is implicitly conveyed because the semantic ground has been established by previous speakers and the current speaker assumes the audience has gained sufficient information to construe the implied meaning (see Anderson, Chinn, Chang, Waggoner, & Yi, 1997). Identifying relational thinking by relational markers might therefore underestimate students' actual relational thinking.

Finally, although there were enough observations for the SAB models to have adequate statistical power based on the multi-group option, the number of individuals within groups was too small to allow analysis of variability at the group level. Hence, possible differences among groups in network dynamics remain unexplored in the present study. Future SAB models of small-group networks need to be extended to account for multilevel data structures.

5. Conclusions

In conclusion, this study documents the proximal effects of friendship and status in the classroom social network on the social and cognitive dynamics of collaborative discussions and enables a fuller understanding of the moment-by-moment and session-by-session processes by which students' reasoning strategies develop during collaborative small-group discussions. The study provides a further warrant for the claim that extended immersion in an intellectually stimulating and socially supportive small-group environment facilitates cognitive development.

This study demonstrates that during Collaborative Reasoning discussions both support and refutation are significant immediate antecedents of relational thinking. Support of others is mainly mediated by friends and students centered in the classroom social network; refutation is mainly mediated by socially centered students and is less likely to be generated by students perceived as quiet. The detailed insight into process afforded by this study stands in stark contrast to traditional instructional research, in which students complete pretests and posttests and, in between, an exceptionally complex process unfolds that is sampled only occasionally, if at all.

This microgenetic study suggests that dialogic interaction among peers is built on existing peer relationships, which in turn affects students' higher-order thinking process. Given that interaction with peers becomes increasingly influential during middle childhood and adolescence, schools should give priority to establishing positive contexts for students to experience peer interaction that leads to cognitive growth.

Acknowledgments

The research reported in this paper was supported by the Institute of Education Sciences, U.S. Department of Education, through Grants [R305T010250, R305G030070, R305A080347] to the University of Illinois at Urbana-Champaign, Richard C. Anderson, Principal Investigator. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education.

Appendix

Summaries of 10 stories in the order discussed

Story	Big question	Content
What Should Kelly Do? (Weiner, 1980)	Should Kelly tell Evelyn about her painting?	A girl, Kelly, 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.
Ronald Morgan Goes to Bat (Giff, 1990)	Should the coach let Ronald play?	Ronald is a boy who makes frequent mistakes when playing baseball and can neither catch nor hit the ball, but he has great team spirit and really wants to play.
The Trip to the Zoo (Reznitskaya & Clark, 2001)	Are zoos good places for animals?	Two girls discuss 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.
Paper Bag Princess (Munsch, 1999)	Should the princess marry the prince?	A princess is going to marry a prince. A dragon comes and burns down their castle and takes away the prince. The princess outwits the dragon and rescues the prince. She has nothing to wear but a paper bag, which is the only thing left after the castle burns. When the prince sees her, he tells her to go away and come back when she dresses herself like a princess.
Marcos' Vote (Nguyen-Jahiel, 1996)	Should Marcos vote for textbooks or computers?	Marcos and Crystal are the two student members of a committee that will make a decision about whether their school should buy a new set of math textbooks or computer software to teach mathematics.
Amy's Goose (Holmes, 1977)	Should Amy let the goose go?	A lonely girl named Amy finds an injured goose. Amy nurses the goose back to health and struggles to decide whether to keep it as a pet in her family's farm or let it fly south with the rest of the flock.
My Name Is Different (Prasad, 1987)	Should Chang-Li have changed his name?	A young Chinese American boy changes his name because he is anxious to fit into his new, mostly Anglo school.

Story	Big question	Content
Stone Fox (Gardiner, 1980)	Should Stone Fox let Willie win?	Willie is a boy who lives with his grandfather, who has been ill and unable to pay the taxes on the farm. Willie enters a dog sled race intending to use the prize money to pay the taxes. His principal competitor is Stone Fox, a Native American man, who usually wins the races and uses the money to buy back ancestral lands. Willie is leading in the race because he has taken a shortcut across a frozen lake when his dog drops dead from exhaustion 10 feet from the finish line.
The Golden Cadillac (Taylor, 1998)	Should the family drive to the south in the gold Cadillac?	An African American family lives in the north of the United States. The father wants to take the family to visit relatives in the South driving a new gold Cadillac, but the South was still racially divided at that time and car might arouse resentment among Southern whites.
The Trail to Willow Valley (Nguyen-Jahiel & Jahiel, 2001)	What kind of power plant should Kate recommend?	An environmental scientist, Kate, is asked to give her expert opinion about the type of power a town should build: a coal-burning plant; a biomass plant; a nuclear plant; a wind-farm; a solar plant.

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