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Relational Reasoning in Medical Education: Patterns in Discourse and Diagnosis

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Relational reasoning, which has been defined as the ability to discern meaningful patterns within any informational stream, is a foundational cognitive ability associated with education, including in scientific domains. This study entailed the analysis of instructional conversations in which an attending clinical neurologist and his team of residents made diagnostic and therapeutic decisions about actual patients in a hospital setting. The primary goal was to investigate the role of 4 manifestations of relational reasoning (i.e., analogy, anomaly, antinomy, and antithesis) in medical education and diagnostic and therapeutic decision making. Results indicated that the degree to which members of the medical team used the 4 forms of relational reasoning depended on their role and expertise, as well as the time point in the problem-solving process. Specific reasoning patterns that emerged in the discourse and a prototypical model of the reasoning process are described and implications for research and practice are considered.

Keywords: relational reasoning, medical education, discourse analysis, apprenticeship model

Relational reasoning has been characterized as the ability to discern meaningful patterns within any informational stream (Bassok, Dunbar, & Holyoak, 2012; Crone et al., 2009; Dumas, Alexander, & Grossnickle, 2013). Moreover, this ability to detect a meaningful pattern from seemingly unrelated information, as well as to derive overarching patterns from sets of relations from different domains, is fundamental to human cognitive functioning (e.g., Krawczyk, 2012) and learning (e.g., Richland, Zur, & Holyoak 2007). Manifestations of relational reasoning have been empirically linked to academic achievement in a variety of domains such as reading (Ehri, Satlow, & Gaskins, 2009), chemistry (Bellocchi & Ritchie, 2011; Trey & Khan, 2008), mathematics (Richland & McDonough, 2010), and mechanical engineering (Vargas Hernandez, Okudan Kremer, Schmidt, & Acosta Herrera, 2012). Although this association between relational reasoning and academic outcomes has been demonstrated, it is less understood how relational reasoning manifests within instructional conversations between an acknowledged mentor and those seeking to learn from that mentor—conversations core to the educational process. In this study, medical diagnostic conversations held between an experienced attending physician and a team of relatively novice residents concerning actual patients in the hospital setting were analyzed with an eye toward how relational reasoning supported medical education and problem solving.

Relational reasoning, as it is defined here and elsewhere (e.g., Bassok et al., 2012; Crone et al., 2009; Dumas et al., 2013; Krawczyk, 2012), requires the discernment of *pattern*. Importantly, the connecting of multiple relations among pieces of information is required for the formation of a pattern (Simon & Lea, 1974). In this way, patterns are inherently composed of relations among relations. These relations-among-relations have often been characterized as *higher order*, because they are derived from a series of *lower order relations*, or simple associations between individual pieces of information (Chi, 2013; Gentner & Gentner 1983; Goswami, 1992). Others (e.g., Sternberg, 1977) have referred to the multiple lower order relations required for relational reasoning as *inferences*, and the higher order patterns derived from them as *mappings.*

Because analogical reasoning, at its core, involves the mapping of higher order relations (Gentner, 1982; Sternberg, 1977), analogy unquestionably fits the definition of relational reasoning. For example, an analogy may be mapped between the atom and the solar system. Specifically, in both of these systems, a comparatively smaller object (i.e., electrons or planets, respectively) revolves around a larger structure (i.e., the nucleus or the sun). Because both the atom and the solar system share these lower order relational attributes, a higher order relation of similarity can be mapped between them, and it can be said that the solar system is, analogically, *like* an atom. Thus, analogies entail the recognition of

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relational patterns of similarity between two or more seemingly disparate ideas, objects, or events (Holyoak, 1985; Novick, 1988). The inherently relational nature of analogical reasoning has led some researchers to use the term *analogy* to describe any process in which a higher order relation is mapped (e.g., Hofstadter, 2001), whereas others contend that the broader term *relational reasoning* is more appropriate because it allows for the diversity of mappable relations to be explicitly described (Chi, 2013; Holyoak, 2012).

Although the conceptual inclusion of analogy as an important form of relational reasoning is uncontested, some researchers recently have suggested that there are further types of mappable higher order patterns that are relevant to human cognition in general and education in particular. Thus, focusing strictly on analogies may restrict what can be learned about human reasoning (Chi, 2013; Holyoak, 2012; Sagi, Gentner, & Lovett, 2012). Rather, these researchers suggest that relational reasoning can be seen as taking different forms depending on the high-order relation being mapped (Dunbar, 2013). Because the type of relational pattern that is ultimately mapped can differ depending on the information at hand, it may be essential to investigate different types of patterns in order to understand and potentially support students' ability to think relationally (Chi, 2013). For example, Alexander and colleagues (2012) have suggested that at least four forms of relational reasoning merit further examination: analogy, anomaly, antinomy, and antithesis. These forms of relational reasoning represent four distinct types of higher order patterns mapped that can be extracted from any informational flow—mappings seen as important for cognition and education (American Association for the Advancement of Science, 1993; Dumas et al., 2013).

Specifically, in contrast to analogy, which is based on relational similarity, anomaly requires the identification of a pattern predicated on unusual or unexpected relations between events, occurrences, or objects. In effect, an anomaly is a relational discrepancy or deviation from an established rule or trend (Chinn & Brewer, 1993; Klahr & Dunbar 1988; Kulkarni & Simon, 1988). As such, the term *anomaly* signifies both a process and a product predicated on a higher order relation of discrepancy, just as *analogy* represents both a reasoning process and product based on a higher order relation of similarity. Thus, when scientists or medical students recognize that data from one or more observations run counter to an expected pattern, such as a hypothesis or diagnosis, these individuals have identified a relational structure that implies the presence of an anomaly. Importantly, anomaly requires numerous lower order relations to be inferred between each element of a set (e.g., patient symptoms) and every other element of that set. If a particular element of the set (e.g., results from a given medical test) relates differently to all other elements than the others do, a higher order relation of discrepancy can be mapped between and among the previously inferred lower order relations, defining an instance of anomaly.

By comparison, reasoning by antinomy requires the identification of a higher order relation of incompatibility, and may involve identifying what a pattern *is* by isolating what it *is not*, or recognizing the mutual exclusivity among relationally defined categories (Chi & Roscoe, 2002; Cole & Wertsch, 1996; Gardner, 1995; Sorensen, 2003). Thus, what marks antinomous reasoning as relational is the requirement to not simply place an object or idea into a mental category, but discern the critical lower order relational attributes that indicate a true incompatibility between that object or idea and all other relevant categories. For example, a biologist attempting to classify a newly obtained insect specimen must not only ascertain the salient attributes of that specimen (e.g., ratio of wingspan to body length) that may suggest membership in a given category (e.g., family or genus) but also determine how certain attributes *exclude* membership in any other categories.

Lastly, an antithesis is predicated on a pattern of directly oppositional relations between ideas, objects, or events (Bianchi, Savardi, & Kubovy, 2011; Kuhn & Udell, 2007; Sinatra & Broughton, 2011). For example, if a molecular biologist observes that introducing a certain gene into one kind of bacterium results in a sharp increase in the bacteria population, but introducing the same gene into a different kind of bacteria has the opposite effect (i.e., decrease in population), she is engaged in antithetical reasoning.

Although each of the forms of relational reasoning considered in this investigation may share overlapping component processes (e.g., encoding, inferring, or mapping; Sternberg, 1977), it is the characterization of the mapped relation that distinguishes one form of relational reasoning from another. Specifically, although each form of relational reasoning requires the mapping of a higher order relation from multiple lower order relations (Goswami, 1992; Markman & Gentner, 2000; Sternberg, 1977), the mapped relation could be one of similarity (analogy), discrepancy (anomaly), incompatibility (antinomy), or opposition (antithesis). Importantly, we do not claim that these are the only types of higher order relations that can be mapped, but contend that these four forms are worthy of investigation because of their broad applicability to educational settings in which complex cognitive processes are required, like the medical education discourse at hand.

Medical diagnostic instructional discourse is particularly suited to the examination of the forms of relational reasoning for several reasons. First, diagnostic discourse such as appeared in the data analyzed in this study, represent a cognitively demanding problem-solving task that is undertaken by a group, allowing instances of relational reasoning to necessarily be verbalized in order to communicate reasoning processes. Further, diagnostic reasoning can be described as "high-stakes" because the lives of patients literally depend on an appropriate conclusion being reached by the medical team. Finally, diagnostic problem solving that occurs with an attending physician and a team of medical residents, such as the interactions analyzed in this study did, represents a critical teaching event, in which a much more experienced individual guides the reasoning processes of his or her students. Educational models like the one being examined in this study, in which a valued task (e.g., patient care) is being undertaken by a group consisting of relatively novice individuals (e.g., residents) and one or more highly experienced instructors (e.g., attending physician), have been termed *apprenticeships* in both the educational literature generally (Rogoff, 1990) and the medical education literature specifically (Bleakley, 2002). A medical apprenticeship is particularly suited for the investigation of relational reasoning because it is a high-stakes context in which reasoning processes pertaining to critical life-and-death situations are by necessity externalized as part of the group discourse.

To our knowledge, although relational reasoning has been implicated as a potentially important ability for medical students and practitioners (Patel, Arocha, & Zhang, 2012; Patel, Dunbar, & Kaufman, 1995; Thagard, 1997), there has not been an empirical examination of the four forms of relational reasoning in the medical domain. As with the research on relational reasoning in other domains, much of the focus within the medical field has been on analogical reasoning. For instance, in their recent review, Pena and de Souza Andrade-Filho (2010) concluded that analogical reasoning plays a role in medical practice and education in a variety of ways, including naming and describing medical phenomena, learning medical concepts, and reasoning about patient cases.

However, there is evidence in the literature on medical reasoning that other forms of relational reasoning may also come into play in medical diagnosis and therapeutic decision making. For example, it has been shown that physicians attend to unusual or unexpected aspects of a patient's physical or mental condition (anomalies) in order to make a diagnosis (e.g., Patel & Groen, 1986). Further, physicians mentally sort patients or their symptoms into categories and use the exclusivity (antinomies) between these categories to help guide their decisions (Eva, 2005). Finally, the ability to weigh the relative merits of two opposing viewpoints or findings (antitheses) may also be beneficial for medical students and practitioners (Boshuizen & Schmidt, 1992).

In the current study, we sought to examine how these four forms of relational reasoning might be evidenced within the diagnostic and therapeutic decision-making process of a medical team. Although other forms of reasoning exist in the literature (e.g., inductive and deductive), we targeted these specific forms because they specify the nature of the association that frames the ensuing relation (e.g., similarity vs. incompatibility) and not solely the process of reasoning (e.g., general to specific or specific to general). Moreover, the approach to analysis we used allowed other forms of relational mapping not considered within the four types to potentially emerge.

Specifically, a detailed analysis of the spontaneous discussions held between a team of medical residents and an attending physician on the diagnosis and treatment of actual patients in the hospital setting was undertaken. These discussions were not orchestrated in any way but unfolded in real time as part of ongoing interactions between an experienced clinical neurologist and the residents apprenticed under him as part of their medical preparation. As Dunbar (1995, 1997, 2001) has argued, the use of what he has labeled an *InVivo* methodology, in which individuals' thinking and reasoning are studied in real time and in real-world contexts, can afford "insights into the basic cognitive mechanisms underlying complex cognition and creativity" (p. 461).

Further, Dunbar and Blanchette (2001) contend that examining the thinking and reasoning of those engaged in high-stakes, cognitively demanding tasks may necessarily require the use of relatively select samples in order to extract meaningful and generalizable patterns. In fact, principles of the reasoning processes used by scientists and students in molecular biology laboratories in the United States, Canada, and Italy (e.g., Dunbar, 2001) have been found to be highly applicable to other learning contexts and domains, such as spontaneous discussions among parents and children at science museums (Atkins, Goudy, Valez, & Dunbar, 2009). However, previous research examining relational reasoning in a naturalistic context has tended to focus on analogy, and to a lesser extent, anomaly (Dunbar, 1995). Here, we extend this methodological focus to other forms of relational thought and their interactions to determine the manner in which relational thinking supports group problem solving and education in a real-world apprenticeship context.

Researching reasoning in a real-world medical context involving experts and those acquiring expertise is a technique that has been used effectively when investigating the complex cognitive abilities needed for medical reasoning (e.g., Gaba, 1992). As such, the efficacy and generalizability of *InVivo* methodology has been previously demonstrated in the medical domain. For example, Patel, Dunbar, and Kaufman (1995) specifically examined the discourse of medical teams working in intensive care units to uncover the effects of distributed reasoning processes on medical thinking. Their findings have generalized to various reasoning contexts, both within and without the medical domain (Patel et al., 2012). Because data gathered using *InVivo* methods represent the actual reasoning processes of a medical team working with real patients, its analysis allows an ecologically valid view of medical reasoning that laboratory experiments cannot (Dunbar, 1995; Patel, Kaufman, & Magder, 1996; Rogoff, 1990).

So, within this naturalistic context, we posed the following three questions about relational reasoning within medical discourse and diagnosis.

1. What occasions of relational reasoning will emerge in the discourse of a mentor attending physician and apprentice residents working to diagnose and treat patients?

In terms of the extant literature, we hypothesized that multiple instances of relational reasoning would populate the discourse of the attending and residents as they worked toward the diagnosis of particular medical cases. Moreover, we expected that more than analogical reasoning would manifest, especially given prior evidence for anomalous thinking in case diagnosis (e.g., Patel & Groen, 1986). However, we were uncertain as to whether all four forms of relational reasoning, previously overviewed, would be present.

2. How does the use of relational reasoning differ quantitatively and qualitatively among the attending and residents based on their experience and role in this medical apprenticeship?

Specifically, given the varied roles and responsibilities of the attending and residents in this unfolding and naturally occurring context, we hypothesized that both quantitative and qualitative differences in the occasions of relational reasoning would be documented. Drawing on the literature in expertise, we expected that such differences would arise when the reasoning pattern of the attending was compared with that of the residents. We were unsure whether differences would similarly arise when the contributions of the residents were the focus of analysis.

3. How do the forms of relational reasoning work in concert as attending and residents work together to diagnose and treat medical patients in their care?

Finally, what we hypothesized was that the instances of relational reasoning would not occur randomly within the conversations between attending and residents. Rather, we expected that these relational reasoning events would themselves form a discernible and logical pattern given the task of moving toward a justifiable diagnosis and relevant treatment protocol. The precise character of that pattern, however, remained to be ascertained.

Method

Participants

One attending clinical neurologist (male), with over 20 years of experience diagnosing and treating neurological conditions, and his team of residents ($N = 9$) participated in this study. Participants worked at a neurological institute and hospital in a large Canadian metropolitan university. The team of residents was predominantly male ($N = 6$) and White ($N = 6$). The remaining three of the residents were of Asian descent. The mean age of the residents was 29.11 ($SD = 1.61$).

Data Source

This study examined the reasoning of a medical team within a teaching hospital. As part of their training, the residents meet regularly with an attending physician. The explicit purposes of these meetings were, at least, twofold. First, through these meetings, the medical team collaboratively considered the conditions and needs of patients in the hospital, leading to diagnostic and therapeutic decisions. Second, it was expected that the residents would garner medical knowledge and skills from their interactions with the attending physician, a clinical neurologist. The meetings took place in a room away from the hospital patients, and were audio-recorded over a 6-week period. The audiotape was placed in the meeting room by a researcher who then exited, allowing the medical team to deliberate freely about the patients.

As part of the routine of these meetings, residents were responsible for initially presenting each new case to the attending, who had not previously been briefed on the case. Specifically, the presenting residents' task was to overview whatever information they perceived as crucial to diagnosing the condition and to formulating the appropriate treatment. Other residents or the attending could freely interject during these overviews by requesting elaboration, raising concerns, or posing alternatives. In subsequent sessions, cases may be revisited as additional information was requested and obtained. After a diagnosis was made and a suitable treatment prescribed, the team would move on to another case.

A total of 11 meetings were recorded, transcribed, and coded. The meetings ranged in length from 25 min to 88 min, with the mean length of the meetings being 51.63 min ($SD = 20.36$). A total of 35 patient cases were discussed during the recorded meetings, with a minimum of one, maximum of seven, and an average of 3.18 ($SD = 2.08$) cases being discussed per meeting. Twenty percent ($n = 7$) of the total discussed cases were revisited at a later meeting, after their initial consideration.

Discourse Codings

The unit of analysis in this study were *conversation units*, defined as each complete thought expressed by an individual (Ford & Thompson, 1996). These units were examined by form and by whether the speaker was the attending physician (AP) or the team of residents (R_1 to R_9).

Nature and form of conversation units. Conversation units theoretically represent the expressed thoughts of a speaker that are generally grammatically comparable to independent clauses and often signaled by a pause or interruption in the flow of discourse (Trickett & Trafton, 2007). A total of 2,114 conversation units were coded over the 11 meetings. Then, the conversation units were coded as either being instances of relational reasoning or not, based on the presence of statements that suggested the speaker was relating two or more objects, ideas, or people in their mind. A total of 272 relational conversation units were identified, whereas 1,842 units were coded as nonrelational reasoning. Those units that were nonrelational reasoning were categorized as either case related (CR) or off task (OT). For example, in one instance, a resident shared specific information on treatment options for a patient: "We expect to extubate her and do a couple of studies and then we can send her back." This unit was coded as CR because it was pertinent to the case under discussion. By comparison, in another instance, the AP said to a resident who was about to share information about a patient: "You've got one minute to catch my interest, otherwise I fall asleep." This statement was coded OT, because it did not deal specifically with the case at hand. Of all the nonrelational reasoning conversation units, 19.92% ($n = 367$) were coded as OT, whereas 80.07% ($n = 1{,}475$), were coded as CR.

The conversation units identified as reasoning related were then coded according to the type of relational reasoning indicated. Given that these coded patterns were all predicated on the careful analysis of patient data (e.g., presenting symptoms, history, and test results), many of the same lower order relations were relevant to the varied forms of relational reasoning that were coded. More precisely, it was the critical, higher order mapping made between bodies of data that determined whether the pattern being identified was one of similarity, discrepancy, incompatibility, or opposition. In effect, it was how these lower order associations were assembled and compared that gave the form its specific character.

For example, conversation units were coded as analogy (AG) if a relational similarity between two or more cases was indicated, as when a resident described the symptoms of a patient as being, "just like post head-trauma seizures." In this example, the higher order relation of similarity being mapped between the observed symptoms of the current case and a previously diagnosed and successfully treated case of posthead trauma seizures defined the conversation unit as analogical. Conversation units were coded as anomaly (AM) if a relational discrepancy was being pointed out between what was observed in the given case and what would be typical or expected in patients. For example, when a resident stated, "those findings aren't going to be found in normal individuals." Thus, units that referenced findings that were unusual or unexpected or that expressed surprise about a given finding on the part of the speaker were categorized as anomalous.

Conversation units were coded as antinomy (AN) whenever mutually exclusive categories were being described, such as when the attending physician instructed the residents to, "separate out people with preexistent structural lesions and people that did not have structural lesions." As this example implies, units in which speakers were demonstrating that they had judged a patient's symptoms as being incompatible with a given pathology or condition were coded as antinomous. In particular, the previous example required the medical team to consider the results of several medical tests across multiple patients, and then infer the relations among these results. If a pattern of results emerged that was incompatible with a given patient having preexistent structural lesions, the decision was made to exclude the patient from that category.

Conversation units were coded as antithesis (AT) whenever two directly opposing ideas were forwarded and discussed in contrast. For example, after hearing the diagnostic opinion of one of the residents, the attending physician asked the group: "Anybody want to take the opposite stance?" As in this example, instances of antithesis required the speaker or listener to reverse the particulars of a given process or argument in their mind, produce an oppositional concept, and then decide whether that oppositional idea would be an appropriate explanation for the scenario being discussed.

It was determined that all instances of relational reasoning could be sorted into one of the four existing categories. That is, no conversation units were designated as unclassifiable or found to signify some alternative form of relational reasoning. A specific segment of transcript is displayed in Figure 1 along with the codes applied. In this example, each conversation unit is set off by dashes (/), and the type of unit is indicated by the codes found directly above the text. In these data, none of the participants offered a relational statement concerning something other than the specific cases at hand. Thus, none of the conversation units were coded as both relational *and* off task.

Attending and resident conversation units. Instances of each form of relational reasoning were further separated on the basis of whether they were voiced by the attending physician, or by one of the residents. Previous empirical examinations of relational reasoning (e.g., Dunbar & Blanchette, 2001; Schunn & Dunbar, 1996) have shown that the line between *communicating* relational thoughts in conversation and *reasoning* with relations is blurry at best, with relational mapping generally being elicited automatically when a higher order relation is drawn in discourse, regardless of the goals (instructional or otherwise) of the speaker. As such, the attending physician's conversation units were not separated on the basis of their diagnostic or instructional purpose, but were described in regard to the form of relational thought being engaged in. However, differences in the patterns of relational units between the attending and the residents are discussed in terms of the role and experience of the speaker.

Interrater agreement. The first and fourth author independently coded two (18%) of the transcribed meetings to delineate the conversation units and to mark each unit according to the coding scheme. The interrater agreement ($\kappa = .88$) was considered good (Cohen, 1968). Then, a research assistant blind to the experimental design and research questions independently coded transcripts from six (54%) of the meetings, none of which had been coded by the fourth author. The interrater agreement between the research assistant and the first author was also good ($\kappa = .82$). The reliability statistics presented here account for coding decisions related to (a) the designation of units as relational and (b) the categorization of relational units into the forms of relational reasoning. Whenever multiple coders disagreed on the designation of a given unit, the disagreement was resolved through discussion until each of the formerly disagreed-upon units were given finalized codes on the basis of consensus. With the reliability of the coding scheme established, the first author coded the remainder of the meetings.

Results and Discussion

Quantity and Form of Relational Conversation Units

Results pertaining to the quantity of relational units for the entire medical team are presented first. Then, results corresponding to the medical residents and the attending physician are presented separately. Our first research question focused on the occurrences of relational reasoning within the discourse of an attending and residents apprenticing under him. To address this

CR
AP: / Do you think the people who are studying the symmetrical polyneuropathy will accept what you're saying? /

AG
R$_5$: It's very…it's…I'm thinking of it as a resemblance to the current thinking now with lipids and the coronary arteries and why they're recommending treating post primary events with lipid lowering medications… / because the papers now keep showing that
AT
high LDL affects coronary vasculature in such a way that rather than dilating response to
CR
silicone and nitric acid its actually constricting / …and they've routinely shown this. / And
AG
it sounds like it's very much the same idea that you're altering the local biochemical auto regulation of the vasculature with a biochemical disturbance / …it's very much along a
AG
similar way of thinking.

Figure 1. An example of the procedure applied in identifying and coding conversation units. CR = case related; AP = attending physician; AG = analogy; AT = antithesis; R = resident.

question, we first examined the data for the entire team, regardless of role or experience, followed by separate analysis for residents and the attending.

Full medical team. As noted, 2,114 conversation units were identified across the 11 meetings, with a mean of 192.18 (SD = 87.82) units per meeting, with a total of 272 (12.86%) coded as instances of relational reasoning. The mean number of instances of relational reasoning per meeting was 24.72 (SD = 13.10), with a range of 8–48 such utterances per meeting. Of the identified instances of relational reasoning, 22.79% (n = 62) were analogical in nature, 58.72% (n = 157) dealt with anomalies, 17.27% (n = 47) with antinomies, and 2.20% (n = 6) with antitheses. As noted, of the remaining units identified, 80.07% (n = 1,475) were case related, and 19.92% (n = 367) were off task. Consistent with our initial hypothesis, there were frequent occasions of relational reasoning within the conversations between attending and residents about the diagnosis and treatment of patients. Also, as hypothesized, we documented multiple forms of relational reasoning within the 11 meetings. In fact, all four forms of relational reasoning were coded, although anomaly was the most prevalent and antithesis was the least occurring form.

Residents. The team of residents articulated 59.83% (n = 1,265) of the total conversation units across the 11 meetings, with a mean of 115.00 (SD = 54.65) units per meeting. The residents offered 67.27% (n = 183) of the identified instances of relational reasoning, with an average of 16.63 (SD = 11.81) instances of relational reasoning per meeting. On average, 14.46% (SD = 5.94) of the conversation units spoken by the residents per meeting were relational in nature. Of the residents' instances of relational reasoning, 13.66% (n = 25) were analogies, 77.59% (n= 142) were anomalies, 7.65% (n = 14) antinomies, and 1.09% (n = 2) antitheses. Of the residents' nonrelational reasoning conversation units, 80.12% (n = 867) were coded as case related, and another 19.87% (n = 215) were categorized as off task.

Attending physician. Across the 11 meetings, the attending physician offered 40.16% (n = 849) of the total conversation units, with 77.18 (SD = 39.70) conversation units per meeting on average. The attending physician voiced 32.72% (n = 89) of the identified instances of relational reasoning, with a mean of 8.09 (SD = 2.66) relational units per meeting. On average, 10.48% (SD = 3.44) of the conversation units expressed by the attending physician per meeting were relational. Of the attending's identified instances of relational reasoning, 41.57% (n = 37) were analogies, 16.85% (n = 15) were anomalies, 37.07% (n = 33) were antinomies, and 4.49% (n = 4) were antitheses. Of the attending's nonrelational reasoning conversation units, 80.00% (n = 608) were categorized as case related, and another 20.00% (n = 152) were coded as off task.

Importantly, although these results show that the attending physician contributed fewer conversation units per meeting than the group of residents, the residents are nine individuals, whereas the attending is only one. Complete counts of conversation units for the attending physician as well as each individual resident are available in Table 1. In these data, the relative proportion of conversation units contributed by the attending was significantly greater than for any of the individual residents, $\chi^2(1, N = 2,114) = 2,136.72$, $p < .001$, with the attending contributing 40.16% of the conversation units, and the single resident who spoke the most over the course of the meetings (i.e., resident number seven), contributing only 11.40% (n = 241 units).

Relational Reasoning and Diagnostic Role

The second research question guiding this investigation explored whether there were quantitative and qualitative differences in the occasions of relational reasoning for the attending physician and residents he sought to mentor in medical diagnosis. We considered this question of quantitative and qualitative differences in two ways. First, we compared the discourse pattern of the attending in contrast to the group of residents. Then, we sought to determine whether there were quantitative and qualitative differences in relational reasoning among the individual residents.

Differences between the attending and residents. To ascertain whether level of experience affected the way relational reasoning was used in this particular context, frequency of usage of the forms of relational reasoning for the team of residents and the attending physician were compared. Specifically, chi-square tests of independence were used to ascertain whether the residents, seeking to increase their skills at medical diagnosis and therapeutic decision making, used the forms of relational reasoning in different proportions than the much more expert attending physician.

Because the residents and the attending physician did not speak the same amount during the meetings, and therefore could not be reasonably expected to have produced the same number of instances of relational reasoning, the chi-square tests compared the observed frequencies of conversation units of each form of rela-

Table 1
Frequency of Relational Conversation Units

Type of conversation unit	Frequency of units											
				Individual residents								
	Full medical team	Attending physician	All residents	1	2	3	4	5	6	7	8	9
All units	2,114	849	1,265	128	162	135	109	197	88	241	82	123
Off task	367	152	215	23	19	39	11	32	6	61	9	15
Case related	1,475	608	867	87	109	80	88	145	61	152	56	89
Relational reasoning	272	89	183	18	34	16	10	20	21	28	17	19
Analogy	62	37	25	3	4	2	1	3	2	5	3	2
Anomaly	157	15	142	14	27	11	9	15	16	21	14	15
Antinomy	47	33	14	1	3	2	0	1	3	2	0	2
Antithesis	6	4	2	0	0	1	0	1	0	0	0	0

tional reasoning (see Table 1) with expected frequencies on the basis of the relative proportion of conversation units produced by the residents and the attending physician, respectively. Thus, because the team of residents generated 59.83% of the total conversation units, they were expected to have the same proportion of instances of relational reasoning. In the same way, the attending physician was expected to have offered 40.16% of the instances of relational reasoning. Conversation units pertaining to antithetical relations were excluded from this analysis because they did not meet the assumptions of the chi-square test of independence (expected frequencies of each of the cells were less than five). Later, we forward a rationale for the limited occurrence of antithetical reasoning within the particular context. Further, instances of CR and OT were not considered as part of this analysis.

The omnibus chi-square test of independence, including proportions for each of the forms of relational reasoning, indicated that the proportion of relational conversation units between the residents and the attending physician was significantly different than would be expected, $\chi^2(5, N = 266) = 88.76$, $p < .001$. Specific chi-square tests of independence for analogy, $\chi^2(1, N = 62) = 9.84$, $p = .002$; anomaly, [$\chi^2(1, N = 157) = 61.08$, $p < .001$; and antinomy, $\chi^2(1, N = 47) = 17.67$, $p < .001$, reveal that this pattern of significance held across these three forms of relational reasoning.

Importantly, the nature of the difference between the observed and expected frequencies of relational conversation units that emerged from the chi-square analysis differed between the particular forms of relational reasoning, based on the role of the speaker within this diagnostic session and potentially their corresponding expertise. Specifically, the attending physician articulated significantly more instances of analogical and antinomous thinking than statistically expected on the basis of the overall proportion of conversation units attributed to him. Conversely, the team of residents expressed significantly more anomalies than statistically expected.

For example, the team of residents often pointed out anomalous aspects of cases such as: "With the CT scan being negative, and with no history of migraine, it was a bit weird that this lady was having this bad of a headache." However, the attending physician more commonly generated analogies (e.g., "Some people have drawn the analogy between an aneurysm and a balloon . . . just stick a pin in the balloon"), antinomies (e.g., "There's two major sides to this discussion, and they may be mutually exclusive"), and antitheses (e.g., "We have a CT scan to go over . . . the doctors in New York say they can take it out, and he sent the films to San Francisco and they said the opposite—'leave it alone'").

Thus, as hypothesized, there were documented quantitative and qualitative differences in the instances of relational reasoning contributed by the attending and group of residents during the diagnostic meetings.

Differences among individual residents. In the previous analysis, the nine residents were treated as a group. Although this method was effective in comparing the team of residents' pattern of relational reasoning with that of the attending physician, further analysis was needed in order to address potentially important individual differences in the usage of relational reasoning among the residents. To support this analysis, the relational conversation units voiced by each of the residents was tallied and sorted by type. For complete counts of conversation units of each form of relational reasoning attributed to each resident, see Table 1.

Quantitative differences. A chi-square analysis was used to determine whether each of the residents offered an equal number of total conversation units during the meetings. This analysis compared the observed total conversation units for each resident with a null condition in which all the residents contributed equally. In the null condition, it was expected that each resident would have voiced one ninth of the total conversation units offered by all the residents, or 140.55 units each. The significance of this chi-square test, $\chi^2(8, N = 1{,}265) = 152.56$, $p < .001$, suggests that residents did not contribute equally to the total conversation units. For example, Resident 6 offered only 88 conversation units over the course of the meetings, whereas Residents 7 and 5 voiced 241 and 197 units, respectively. This pattern shows that quantitative differences did exist in this data set in terms of the quantity of conversation units produced by each resident.

Qualitative differences. To address the potential for qualitative differences in the relational reasoning episodes voiced by the individual residents, we looked first at the relative proportion of their discourse that was specifically relational in nature. Second, we targeted those instances of relational reasoning to determine whether there were discernible differences in the forms of reasoning that each resident contributed in the diagnostic meetings.

In this data set, 14.46% of the conversation units produced by the team of residents were relational in nature. Therefore, that proportion formed the basis of the null condition against which the observed proportion of relational units for each of the residents was compared. This chi-square test was found to be significant, $\chi^2(8, N = 183) = 18.5$ $p = .017$, indicating that certain residents voiced proportionally more relational units than others. For example, Resident 6 verbalized 21 relational units (23.86% of their total units), whereas Resident 4 offered only 10 relational units (9.17% of their total).

To address the question of potential form differences, nine chi-square tests were performed. Each of these tests compared an individual residents' proportion of relational reasoning forms with a null proportion that corresponded to that of the team of residents as a whole. In this data set, 13.66% of residents' relational units were analogical, 77.59% were anomalous, 7.65% were antinomous, and 1.09% were antithetical. In this analysis, antithetical units were not included, because they did not meet the assumptions of the chi-square test of independence (expected frequencies in each of the cells was less than five). None of these nine chi-square tests were significant. This pattern suggests that although qualitative differences existed in the quantity of total conversation units voiced by the individual residents, as well the proportion of those conversation units that were relational in nature, no significant differences in the proportion of use of the forms of relational reasoning among the individual residents was found.

Patterns of Relational Reasoning

The third research question that framed this study sought to determine whether there were any discernible patterns in relational reasoning occurrences that populated the discourse within the diagnostic meetings. To investigate whether the forms of relational reasoning arose in the conversation between the residents and the attending in any discernable pattern, a transition matrix was created (see Table 2). In this matrix, the rows represent the frequency at which a particular form of relational reasoning *preceded* another form in conversation. Conversely, the columns represent the frequency at which a particular form of relational reasoning was *preceded by* another form within the flow of conversation. Importantly, the initial relational unit in each meeting is not represented, in the transition matrix, because cross-meeting transitions were not included in this analysis, so the total number of transitions in the matrix is 261. Moreover, unlike the previous analysis of the proportional use of the forms of relational reasoning, this transition analysis was not broken down by speaker (i.e., attending or resident) because the transitions between the instances of relational reasoning being examined here arose in natural discourse between all members of the medical team, resident and attending alike, so it may not be valid to separate them in analysis (Dunbar, 1995).

Chi-square tests of independence were used to ascertain whether the frequencies of the transitions among the particular forms of relational reasoning were evenly distributed across all forms. In other words, after a given form of relational reasoning was used in a conversation, was each of the other forms equally likely to arise next? As with the previous chi-square tests, the frequencies associated with antithetical reasoning were excluded from this analysis, because they did not meet the assumptions of the chi-square test.

The significance of the omnibus chi-square test of independence, which included frequencies of transitions among each of the forms of relational reasoning, $\chi^2(4, N = 249) = 43.09$, $p < .001$, demonstrated that these forms did not arise in conversation in an evenly distributed or random way. In particular, the chi-square tests of independence for the transitions associated with anomalous reasoning, $\chi^2(2, N = 149) = 117.35$, $p < .001$, and antinomous reasoning, $\chi^2(2, N = 40) = 17.45$, $p < .001$, were significant, whereas the test associated with analogical reasoning, $\chi^2(2, N = 60) = 0.30$ $p = .86$, was not. These results indicate that the pattern of transitions between relational units differed depending on the form of relational reasoning.

Specifically, the nonsignificance of the chi-square test of independence associated with analogical reasoning implied that no definitive pattern as to which form of relational reasoning likely precedes an analogy can be drawn from these data. Rather, instances of analogical reasoning were relatively evenly distributed throughout the diagnostic conversations. This even distribution of analogical reasoning throughout the conversations of the medical team suggests that reasoning with relational similarity between two or more cases appears foundational for residents and attending physicians who are working to pinpoint the exact character of a particular case and conceive of suitable treatment options. For example, after a resident made an analogical statement concerning a patient case, (i.e., "I'm relating him to the patient I took care of over at the [hospital name omitted], about who we entertained the same three diagnoses"), the attending physician responded antinomously that aspects of the present case were incompatible with those of the previous case to which the resident was referring, and therefore the resident's referenced diagnoses were *not* tenable.

Table 2
Transitions Between Forms of Relational Reasoning

Form of relational reasoning	Frequency of transitions			
	Analogy	Anomaly	Antinomy	Antithesis
Analogy	21	18	21	1
Anomaly	19	112	18	2
Antinomy	18	21	1	3
Antithesis	3	0	3	0

In contrast, the anomalies that were pointed out by the medical team were much more likely to precede or be preceded by other anomalies than by any other form of relational reasoning. This implies that, as the medical team was discussing a case, the identification of one piece of information that seemed discrepant to the potential diagnosis likely sparked other such thinking on the part of the medical team. Although the medical team was engaged in reasoning with a cluster of anomalies, the interjection of other forms of relational reasoning was relatively unlikely. It was not until a given explication of discrepant information had been sufficiently exhausted by the medical team that other forms of relational reasoning were likely to enter into the conversation. For example, after a resident presented certain anomalous aspects of a highly unusual case (i.e., "He was brought in by the police wandering the street, he was completely unaware of where he was"), another resident pointed out another anomaly with the case (i.e., "He was able to tell me he called 911 yesterday . . . so he was able to remember that . . . it doesn't make sense . . . he shouldn't know that, but he did").

In contrast to anomalies, instances of antinomous reasoning almost never co-occurred. Instead, in these data, antinomies generally preceded or were preceded by analogies or anomalies, and almost never another antinomy. This suggests that whenever the medical team described what a given case *was not*, it became immediately necessary to begin to describe what they believed the given case actually *was*, either by attending to the relational similarity between the given case and a previous one or by pointing out what was still unexplained or discrepant about the case. For example, when one resident expressed the antinomy about a patient's condition (i.e., "This is not a pneumonia"), another resident immediately followed by pointing out a potentially anomalous aspect of the patient's treatment (i.e., "Then why was the decision needed to admit him?").

Differences in transition length. Although the previous transition analysis yielded findings concerning the pattern of transitions between the forms of relational reasoning, it did not provide information about the relative number of conversation units that these transitions encompassed. In order to address this issue, the number of conversation units between each instance of relational reasoning was tallied and organized on the basis of the type of transition (e.g., analogy to analogy, analogy to anomaly) that was represented. In this investigation, the question was asked: "Do the instances of relational reasoning occur in evenly spaced intervals, or do they occur in some other pattern?" Because the counted conversation units for each transition type could not be reasonably expected to approximate normality (Winkelmann & Zimmerman, 1995), a nonparametric approach to analysis was undertaken.

Specifically, Wilcoxon's signed-rank tests were performed to compare the median length of each transition type with a constant value representing the null hypothesis. This null value was derived by dividing the total number of conversation units in these data (2,114) by the total number of relational units (272) to get the number of units that would fall between each instance of relational reasoning if they were evenly spaced throughout the diagnostic conversations (7.77). A full listing of the counts, medians and associated interquartile ranges, as well as the Wilcoxon's signed-rank test can be found in Table 3. Those transitions not depicted in the table did not meet the requirements of the Wilcoxon signed-rank test (i.e., an *N* of at least 3), this analysis was only conducted on transitions that appeared more than three times in the data set.

The significance of each of the Wilcoxon signed-rank tests associated with transitions involving anomalies suggests that instances of anomalous reasoning emerged both more quickly after other instances of relational reasoning, and other instances of relational reasoning appeared more quickly after them than would be observed with an even distribution of relational units throughout the discourse. Conversely, transitions between analogies and antinomies arose in a more evenly spaced pattern. This finding is consistent with the earlier analysis that suggests that anomalies tend to cluster together within the conversation, appearing in relatively quick succession from one another, whereas the other forms of relational reasoning tend to arise, and transition into each other, less frequently and at a slower pace.

One potential explanation for this observed pattern is related to the speaker voicing each relational unit. Specifically, because the residents tended to produce a significantly higher proportion of anomalies than the attending, and there were nine residents in this sample and only one attending, instances of anomalous reasoning were likely to arise more often and in quicker succession than the other forms. However, instances of analogical or antinomous thought, which were more likely to be used by the attending physician, were voiced more rarely and in a more evenly spaced pattern than anomalies.

Diagnostic and therapeutic decision making as a relational process. In order to describe the diagnostic and therapeutic decision-making process in terms of the relational reasoning in which the attending physician and the team of residents were engaged, a flowchart was created (see Figure 2). This flowchart is an idealized representation of the patterns between and among the relational reasoning forms as they unfolded in the analyzed discourse. The flowchart is intended to visually summarize the previous analyses in this investigation and facilitate the discussion of the uncovered patterns. Importantly, this flowchart does not represent any one particular meeting, but endeavors to highlight reasoning patterns repeated across the 11 meetings.

Specifically, patterns concerning the number and form of instances of relational reasoning spoken during the meetings, differences in relational reasoning use based on speaker role, and trends in the manner in which the forms of relational reasoning transitioned during case discussions, formed the basis of the reasoning flowchart. Because this analysis focuses on the role of relational reasoning in medical education discourse, the flowchart focuses solely on these instances. However, the median lengths of the transitions between each form of relational thinking are available in Table 3.

Specifically, on the far left of the flowchart, the process of making diagnostic and therapeutic decisions typically began by the designated residents first overviewing the data that had already been collected on a particular patient. These preliminary data often consisted of lists of symptoms, current medications, test results, and other relevant information, but varied widely depending on the amount of time the medical team had been treating the patient, or the particular procedures or tests that had been done with patients. The degree to which the presented case deviated from the more common or routine cases entering the hospital also influenced the time devoted to that case, the instances of reasoning that emerged, and the need to gather more information or propose alternative diagnoses. After these preliminary data were overviewed, the team of residents generally began to point out which aspects of those data were unusual or discrepant from what would usually be expected. The attending physician may point out an anomaly as well, but more often the residents took the lead role in this task. This observed pattern does not necessarily mean that the attending physician was unaware of the anomalous aspects of any individual patient case, but rather that the residents more often verbalized these anomalies. Indeed, it is likely that certain aspects of a patient's condition may seem anomalous in the point of view of those who are relatively novice in the medical domain, and therefore have a smaller cache of prior knowledge to draw on, whereas to the more expert attending physician, these aspects may not be unexpected or unusual, and therefore not anomalies to begin with.

As a cluster of anomalies in the patient data began to cohere into a recognizable pattern, the attending physician often inserted himself into the process. Dunbar (1997) observed a similar pattern among scientists when they observed a number of unexpected findings in the data, leading to the generation of a new hypothesis. At this juncture, the attending physician tended to use an antinomy to describe what the patient's condition *was not*, before drawing an analogy between the current patient and another similar case that the group had dealt with previously. This relational process is consistent with the process of *differential diagnosis* described by Patel, Groen, and Arocha (1990), in which a medical team must

Table 3
Wilcoxon Signed-Rank Test for Transition Length

Initial form	Second form	*N*	Median transition length	Interquartile range	*Z*	*p*
Analogy	Analogy	21	7.0	4.0	−1.164	.246
	Anomaly	18	5.5	6.0	−2.025	.042*
	Antinomy	21	8.0	2.5	−0.365	.718
Anomaly	Analogy	19	6.0	3.0	−2.803	.005**
	Anomaly	112	4.0	4.0	−9.066	<.001**
	Antinomy	18	6.0	5.0	−2.678	.007**
Antinomy	Analogy	18	7.0	5.0	−1.24	.215
	Anomaly	18	4.5	4.25	−3.33	<.001**

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

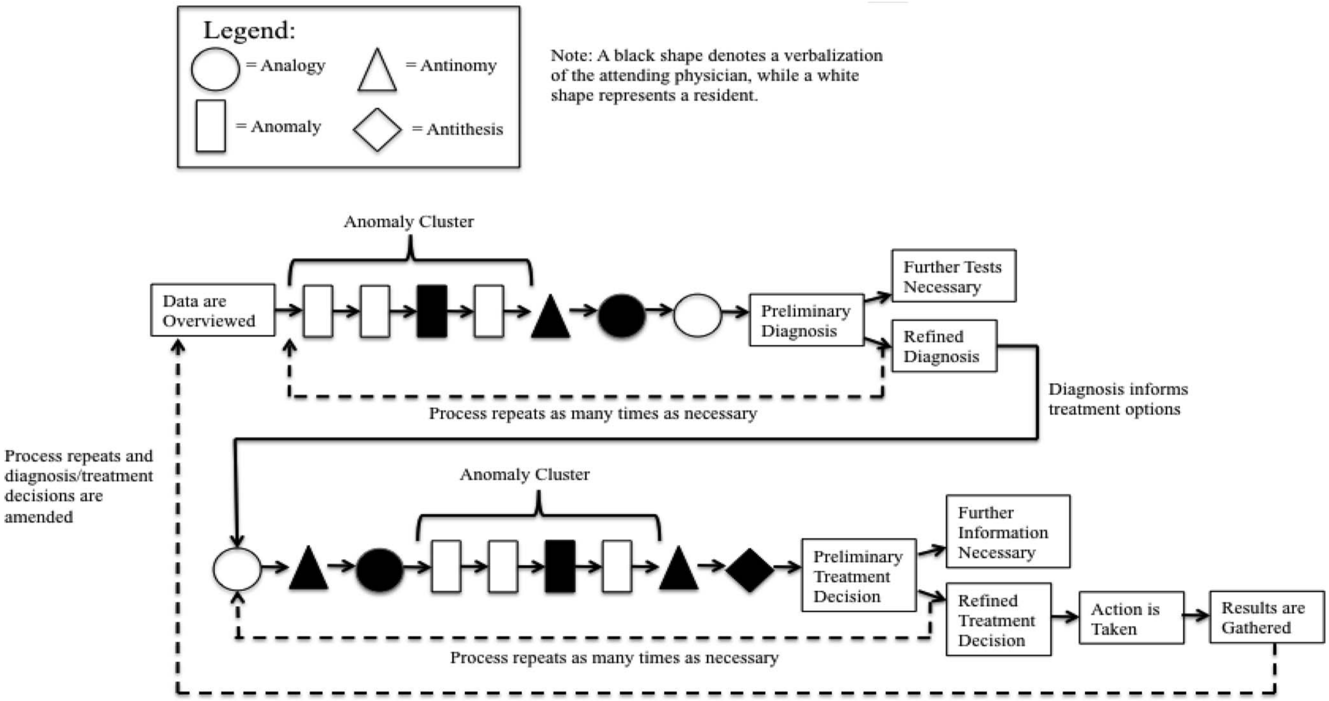

Figure 2. Diagnostic and therapeutic process flowchart. This figure indicates the patterns in relational reasoning episodes that occurred during case analysis.

rule out various possible conditions before a correct diagnosis can be reached.

Once the team of residents acknowledged the analogy offered by the attending, a preliminary diagnosis was often put forward. For example, at this point in one of the meetings, a resident describing a patient's condition interjected: "I'm thinking this is a lymphoma." Importantly, if there were anomalous or as-yet-unexplained aspects of the patient's condition that did not support this preliminary diagnosis the process of identifying anomalies would often begin again, and be repeated as many times as necessary until a refined diagnosis— one that the entire medical team agreed made sense given the information at hand—was produced. If it became apparent that there was a gap in the medical team's knowledge about the patient's condition, or if a precise diagnosis hinged on specific information that was not yet gathered, the residents or the attending typically called for further tests, and returned to that case at a later session.

Once an accepted diagnosis was produced, the medical team usually began to discuss treatment options for the patient. At this point, a resident might refer analogically to a similar case that they had observed in order to suggest a treatment that appeared warranted. In such instances, the attending physician might pose an antinomy to demonstrate how the current patient was not like the previous one, or how the current patient was actually more similar to a different previous case (e.g., "You have to look at [different cases] . . . it's not a pneumonia, so what is the best way to address this?"). At this juncture in the discussion, anomalies were likely to arise, given that the target patient could be presenting with certain symptoms or have a specific medical history (e.g., allergies to medication, other existent complications or conditions) that would render the suggested treatment risky or untenable. For example, an alternative to the typical course of treatment for the symptoms of the previously mentioned patient, who was found disoriented and wandering the streets, needed to be considered, because it was the opinion of the team that he was unlikely to remember to take his medication regularly.

After these anomalies had been examined, an instance of antinomous reasoning might be used to describe what treatments were not appropriate for the patient (e.g., "Birth control pills are an absolute contraindication in somebody with that type of past medical history"). Further, if oppositional stances or interpretations arose concerning the best treatment for the patient, this antithetical interjection had to be considered by the team until either a compromise was reached or one of the opposing positions was deemed preferable. For example, when an individual could have been treated as either an out- or in-patient, the attending asked a resident, "So what would you do with him? Send him home or bring him in?" At this point in the diagnostic routine, a preliminary treatment decision might well be offered. For example, a resident said: " . . . put her on an Aspirin regimen . . . two a day." The reasoning process was repeated until the other team members, or the attending physician, agreed on a final treatment decision.

Alternatively, during this phase of the meeting, the team could decide that more information was necessary before a course of treatment could be determined. For example, another doctor might need to be consulted, or the potential effects of a certain drug in combination with the patient's current medication had to be researched. After a refined treatment decision was produced, action was taken to administer the treatment to the patient and discussion of that case ceased. Later, this case might be revisited as the effects of the treatment were shared with the group at a subsequent meeting. In this way, the relational process of making diagnostic and therapeutic decisions repeated until the patient eventually improved and was discharged from the hospital, or otherwise left the care of the medical team.

This overviewed reasoning process, and the flowchart that accompanies it (see Figure 2), although potentially useful in understanding the thinking and learning of medical residents and attending physicians, does have its inherent limitations. For example, the conclusions drawn about the usage of the forms of relational reasoning are based on the particular context and domain (i.e., in-patient clinical neurology) in which this study was conducted, and patterns of usage of forms of relational reasoning may arise differently in different contexts and with different individuals. Moreover, the explanation of the flowchart offered here does necessarily draw on previously published literature on medical reasoning (e.g., differential diagnosis; Patel, Groen, & Arocha, 1990) to form reasoned inferences about how the observed usage of relational reasoning may correspond to widely recognized diagnostic procedures. Further investigations will likely be necessary to determine the generalizability of this theoretical flowchart.

Conclusion and Implications

As the findings of this investigation suggest, relational reasoning may support the thinking, learning, and communication of students and instructors in the medical and potentially other cognitively demanding domains. In a broad way, the results of this study corroborate findings from previous work both inside and outside the domain of medicine that have implicated relational reasoning as fundamentally supporting complex problem solving in a real-world setting (e.g., Patel, Dunbar, & Kaufman, 1995; Trickett, Trafton, & Schunn, 2009). However, to our knowledge, this investigation was the first to explicitly investigate the differing roles of four different forms of relational reasoning (i.e., analogy, anomaly, antinomy, and antithesis), as well as the patterns in the usage of these reasoning forms. Specifically, the proportional and transitional analyses done in this study allowed for the characterization of a medical team's diagnostic and therapeutic decisions about a patient to be suitably characterized as a relational process.

Although many previous scholarly efforts in the field of medical education have centered around questions of deduction, induction, and abduction (e.g., Elstein, 2009; Elstein, Shulman, & Sprafka, 1978; Magnani, 1992), or distributed reasoning among individuals (e.g., Patel et al., 1995), focusing attention on the four forms of relational reasoning brought overarching patterns within the process of medical education to the fore. Here, we consider four of those overarching patterns that we believe have implications not only to discourse between attending and resident physicians during diagnostic meetings but also to teachers and students engaged in problem solving within the classroom context.

Overarching Patterns

One of the most clearly distinguishable patterns in these data can be broadly summarized as: *Critical analysis of information appears to entail multiple forms of relational reasoning.* There is little question that analogical reasoning is a mark of critical analytic thinking and academic performance (e.g., Bassok, Dunbar, & Holyoak, 2012; Richland et al., 2007). Yet, although the literature on relational reasoning in education and problem solving has long focused principally on analogical relations (Chi, 2013), results from this study suggest that a greater diversity of relational mappings may further enrich critical analytic thinking and learning. In this study, four forms of relational reasoning (i.e., analogy, anomaly, antinomy, and antithesis) were present in the meetings being examined. Although further research is necessary to determine whether these forms of relational reasoning manifest themselves similarly across diverse domains and tasks, it is clear that focusing on analogies alone may limit our understanding of relational thinking in educational contexts.

A second summarizing statement that can be drawn from these analyses is that: *Significant quantitative and qualitative differences exist among individuals in their use of the forms of relational reasoning for problem solving and communication.* This principle is supported by the analysis in this study pertaining to the documented quantitative and qualitative differences between the attending physician and residents, as well as among the individual residents. Specifically, the attending physician was more likely to voice analogies or antinomies than to point out anomalies in patient cases. This distinct pattern of usage of relational reasoning represented a significant qualitative difference between the attending and residents. Although divergent patterns between expert instructors and relatively novice apprentices may exist across contexts, it is likely that, regardless of domain, quantitative and qualitative differences between instructors and students in their ability to use relational reasoning will exist.

Further, we observed significant quantitative differences among the nine residents in terms of their total contributed conversation units, as well as the relative proportion of those units that were relational in nature. However, in these data, no significant qualitative differences were found in the pattern of usage of relational reasoning forms. That is to say, each of the residents followed approximately the same pattern of usage of relational reasoning forms, in which he or she favored the verbalization of anomalies over each of the other forms of relational reasoning.

These observed quantitative and qualitative differences between the attending and residents leads to the idea that: *Given their role and experience, those in the position to scaffold or apprentice the thinking of others may rely on certain forms of relational reasoning more than others*. Support for this principle can be found in the observed pattern that the attending physician, who operates as an instructor for the team of residents, tended to offer analogical or antinomous mappings more than anomalies, which were more often voiced by the team of residents. In particular, the attending often drew analogous or antinomous patterns after the residents had identified anomalous aspects of a particular patient's case, as a way to guide them in the diagnostic process. With these findings, this investigation coheres with many other previous studies (e.g., Richland & McDonough, 2010; Tzuriel & Shamir, 2010) that have revealed that instructional analogies support learning in a variety of domains and grade levels.

This observed difference in the usage of relational reasoning between the highly experienced attending and the more novice residents also coincides with the long-standing cognitive principle that experts in any domain think differently than novices (Chase & Simon, 1973; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Ericsson & Smith, 1991). Moreover, although the ability of an experienced physician to guide the thinking of students through the use of relational reasoning has not, to our knowledge, been studied, it could be that profiles of relational reasoning use changes as individuals gain expertise in a particular domain. Specifically, in the medical domain, it may be that relatively novice residents rely on anomalous aspects of cases to support their diagnostic and therapeutic decision making. However, as these newly minted physicians gain experience diagnosing and treating patients, the formulation of more analogical and antinomous relations may emerge. Understandably, a resident may not yet possess the rich case histories of a highly experienced and acknowledged expert in the field that would be foundational to more analogic or antinomous thinking.

A final statement that can be offered here is that: *The forms of relational reasoning may not arise in isolation, but seemingly operate in concert with one another.* It has long been accepted that instances of relational reasoning require an orchestration of both lower order and higher order associations (e.g., Goswami, 1992; Holyoak, 2012; Markman & Gentner, 2000). Yet, in this study, we also found that when a complex problem-solving task is engaged, there is a good likelihood that multiple forms of relational reasoning are evoked in a logical and informative manner.

In this investigation, the transition analysis as well as the resulting flowchart attempted to capture the ways in which the forms of relational reasoning operated together. For example, it was observed that instances of anomaly were likely to arise in clusters, with analogies and antinomies arising directly afterward. This pattern of anomalies leading to anomalies, and then to series of other forms of relational reasoning implies that the recognition of these anomalous aspects of a patient's case may have been a necessary precursor to the later reasoning forms. This outcome parallels previous findings by Dunbar (1995) that have shown that anomalies lead to the production of other forms of relational reasoning, such as analogies during problem solving. Of course, the pattern in which the forms of relational reasoning arise in conversation may be dictated by the task, domain, or goals of the reasoning group. Further comparative research is necessary to understand the differences in the usage of relational reasoning among differing domains and tasks.

Importantly, as with other studies that have used an *InVivo* methodology to examine naturally occurring instruction and reasoning (e.g., Patel, Kaufman, & Magder, 1996), the instructional role of the attending physician in these data was highly related with his level of experience. For example, studies of graduate students designing experiments with a professor (e.g., Dunbar, 1995) have highlighted similar relations between instructional role and level of expertise. Although this scaffolding role may be more prevalent in situations in which apprenticeship or mentoring is expressly intended (Bleakley, 2002), it is conceivable that those assuming an instructional role in general may manifest certain relational reasoning patterns required to support the thinking and analysis of those less knowledgeable or less experienced. Consequently, as with the attending physician in this investigation, these educators' interjections into the flow of classroom discourse may have the power to redirect or refocus the thoughts and reasoning of others.

Future Investigations

The relative lack of instances of antithetical reasoning in these data may also be a finding worthy of further discussion and investigation. Although some antithetical relations did arise (e.g., the relation between *dilating* and *constricting* found in Figure 1), these data show that this medical team infrequently relied on antithetical thinking. Importantly, the ability to reason with antithetical viewpoints or identify opposite effects has been described as critical for learning in domains like history (VanSledright, 2008) or climate science (Sinatra & Broughton, 2011). Yet, this ability may be less essential to the process of medical diagnosis where case-based reasoning is more commonplace and determinations are predicated more on specific data rather than counterarguments or refutational statements.

One possible explanation for this observation is that the medical team being studied held a shared set of assumptions regarding the diseases being considered, whereas in domains such as history or climate change, there is considerable debate regarding underlying assumptions, practices, and interpretations, leading to more frequent antithetical thinking (VanSledright, 2008). Indeed, within the medical domain, scientific examination of topics about which there has been little consensus (e.g., AIDS) have frequently involved discussions of antithetical evidence (e.g., Lusso & Gallo, 1995). Thus, the degree to which antithetical thinking is used may depend on the amount of consensus within a given field or topic of inquiry.

Another potential explanation for this observation is that many of the remarkable aspects of patients' condition that led to diagnosis were characterized as issues of magnitude of a particular test result (i.e., anomalies) and not as oppositional to a healthy, baseline patient. For example, the elevated blood pressure of a patient was described by the medical team as anomalous and unexpected, not as antithetical to low or normal blood pressure. However, the way that the medical team used antithetical thinking implies that, whereas it may not have been a commonly used form of relational reasoning in this context, it may nonetheless be important to the conduct of diagnostic meetings. Specifically, antitheses most often arose toward the end of a meeting, as a way for the attending physician to point out oppositional views of the issues at hand. In this way, antithetical reasoning represented a small but potentially important part of the larger relational process. Specifically, antithetical thought may have been used by the attending as an instructional strategy with which to encourage the residents to take oppositional arguments into account.

Further, the relational framework forwarded in this study may serve as an appropriate lens for identifying domain differences in reasoning discourse. For example, the characterization of the relational process by which the medical team reached diagnostic and therapeutic decision about patients depicted in Figure 2 opens the door for comparative questions. For instance, how does the characterization of this process in the domain of neurology parallel those in other medical fields, other scientific fields, and those fields outside of science altogether? How might it change at different levels of schooling or in varying professional scenarios? Do some problem-solving or instructional strategies better facilitate accurate and effective decisions? Each of these questions might be addressed through the use of the relational reasoning framework.

Finally, research designed to address questions such as those just posed may form the basis of systematic efforts to support relational reasoning ability in all students. Given the potentially foundational nature of relational reasoning to human learning and cognitive performance (Gentner, Holyoak, & Kokinov 2001; Goswami, 1992; Richland, Zur, & Holyoak, 2007), the need to pursue such goals seems imperative. However, any future interventions targeting relational reasoning must be guided by detailed analysis of relational thought as it plays out in naturally occurring discourse, or risk divorcing relational reasoning from its application in various educational and professional settings. In this way, findings concerning the nature of relational discourse such as those offered here may serve as guiding principles for future instructional interventions.

Because this study was, to our knowledge, the first to examine the role of four forms relational reasoning in medical diagnostic discourse between an attending physician and a team of residents, it offers novel insights into the interplay of analogy, anomaly, antinomy, and antithesis in a cognitively demanding, high-stakes learning situation. Further, the continued use of the relational lens offered in this study as a framework for examinations of educational discourse may help to illuminate as-yet uncovered patterns in the reasoning of students and their more expert instructors in a wide variety of domains.

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