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Relational Reasoning and Its Manifestations in the Educational Context: a Systematic Review of the Literature

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Abstract Relational reasoning, the ability to discern meaningful patterns within otherwise unconnected information, is regarded as central to human learning and cognition and as particularly critical for those functioning in today's information age. However, the literature on this foundational ability is currently housed within a range of domains of inquiry, where divergent terminology and methodologies are commonplace. This dispersion has made it difficult to harness the power of existing work to inform future research or guide educational practice. In order to address this lack of consolidation, a systematic review of relational reasoning was undertaken. Specifically, 109 empirical studies dealing with relational reasoning in general or one of four manifestations (i.e., analogy, anomaly, antinomy, and antithesis) were analyzed. Resulting data revealed trends across fields of inquiry, including a degree of conceptual ambiguity, conceptual and operational misalignment, and a lack of ecological validity in certain research paradigms. There were also particular forms and measures of relational reasoning that were more commonly investigated, as well as certain domains that were more often studied. Implications for how future research can examine relational reasoning as a multidimensional construct within educational contexts are also discussed.

Keywords Relational reasoning · Analogy · Anomaly · Antinomy · Antithesis

> It operates… uniting in a moment what in nature the whole breadth of space and time keeps separate.
>
> William James (1890), *The Principles of Psychology*, p. 346

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In his *Principles of Psychology* (1890), William James describes a foundational human mental ability used to uncover relations of "differences and similarity" (p. 346) between mental representations. James argues that without such an ability, we would be trapped in a world populated only by isolated stimuli, unable to connect the objects of our perception across time and space. For James, this ability necessarily serves as a starting point for human thinking and learning, as well as a mark of expertise in any domain. While the world has changed dramatically in the 120 years since James's writing, such a mental ability has not diminished in significance. Rather, this ability, termed *relational reasoning*—which can be simply conceived as the ability to recognize or derive meaningful relations between and among pieces of information that would otherwise appear unrelated (Alexander and the Disciplined Reading and Learning Research Laboratory 2012)—may be of even greater importance given the deluge of sensory information confronting members of post-industrial societies.

In effect, the particular confluence of forces that currently shape the educational landscape may contribute to the relevance of relational reasoning in the modern context. For example, today's students are constantly inundated with information, much of it available in milliseconds via the Internet, from the moment they wake up in the morning to the moment they fall asleep at night. While recent research calls into question the ability of students to meaningfully deal with this deluge of information (e.g., Strømsø and Bråten 2010; List et al. 2012), the availability of information continues to grow at an exponential rate (Bohn and Short 2009).

At the same time, despite having near-constant access to the ocean of information available via hypermedia, students in the USA have repeatedly lagged behind other countries in international standardized assessments; a situation that has been much maligned both in the popular media (PBS Newshour Online 2010) and in scholarly writing (Schmidt et al. 1999). This apparent disconnect between the spate of information confronting students and their concomitant ability to organize and use that information effectively to guide their actions and build their knowledge—which some have suggested may be partially explained by differences in instructional emphasis on relational reasoning (Richland et al. 2007, 2010)—begs two questions. First, what cognitive abilities are most useful to students in attempting to derive coherent representations or informational patterns out of this informational torrent? Second, how can these abilities be brought to bear on a range of academic problems to facilitate learning and development?

Granted these questions are large enough to encompass the careers of many dedicated educational psychologists, and fully answering either is well beyond the scope of this review. Nonetheless, the search for answers to these significant enigmas fueled this systematic examination of the literatures relevant to relational reasoning. Specifically, relational reasoning is one cognitive ability that has been put forward as potentially important for those who are part of today's post-industrial societies continually awash in information. This is because, when incorporated into the intellectual habits of students, relational reasoning may prove enabling by supporting the consolidation and coherence of otherwise fragmented information into meaningful and applicable units. For example, accessing information through search engines like Google or Bing can encourage students to deal with information in a piecemeal or superficial way (Fast and Campbell 2004; Griffiths and Brophy 2005), while relational reasoning may counteract this tendency by allowing learners to process material more deeply and to develop more principled knowledge out of seemingly isolated data (Van Gog et al. 2004).

Today, relational reasoning is generally regarded as central to human cognition (Hofstadter 2001) and education (e.g., Richland and McDonough 2010). It has been identified as an important ability associated with early learning (Goswami and Mead 1992) as well as a hallmark of expert performance, especially in scientific domains (Dunbar 1995). The empirical study of relational reasoning has emerged as a burgeoning field in recent years, especially in the field of cognitive neuroscience (Krawczyk 2012). There is also a growing interest in relational reasoning by those in the educational research community (Aubusson et al. 2006), and the construct holds an increasingly important place in educational practice (Stephens 2006).

At the present time, research on the construct of relational reasoning appears to have reached a critical point: one where clarity and theoretical focus will likely fuel innovative programs of study, while vagueness and obscurity on the part of the field will likely result in a fizzling out of rigorous scientific interest in the construct (Knowlton et al. 2012). However, because relational reasoning has been studied in a variety of divergent research paradigms (e.g., neuroscience, cognitive psychology, child development, and educational psychology), achieving theoretical clarity is not a simple task. In essence, the diversity of research perspectives in the literature on relational reasoning potentially contributes to conceptual and methodological confusion (e.g., Tzuriel and George 2009; Volle et al. 2010).

A literature review featuring a close examination of definitions and methodologies would, therefore, be an important step in producing clarity and organization on the part of the field and supporting the communication of researchers across diverse research perspectives. However, to our knowledge, a review that seeks to examine the currently existing literature on relational reasoning as it pertains to learning and development has not been attempted. So, because of relational reasoning's potential importance to the educational context of today, as well as the pivotal moment that the field finds itself in, we determined that a systematic review of the extant empirical literature on relational reasoning as it pertains to learning and development was warranted.

While a review of literature on relational reasoning has recently been published in the field of cognitive neuroscience (Krawczyk 2012) and a handbook chapter on the topic has also recently appeared (Holyoak 2012), the present review differs from these publications in several significant ways. For one, those prior examinations of relational reasoning were more specialized in terms of the arena of inquiry (i.e., neuroscience; Krawczyk 2012), or were intended to summarize particular programs of research (i.e., Holyoak 2012). In addition, these prior reviews were centered on one particular form of relational reasoning (i.e., analogical reasoning) and did not broadly consider interdisciplinary publications or multiple manifestations of relational reasoning. In contrast to those prior reviews, we set out to gather literature from diverse fields of inquiry and bring them together to be analyzed, as well as include publications representing four particular manifestations of relational reasoning (i.e., analogy, anomaly, antinomy, and antithesis). Another characteristic of the prior reviews was their more traditional (i.e., non-systematic) approach to literature identification. In this investigation, we systematically gathered literature using an online database by means of theoretically derived search terms. Further, neither of the previous reviews examined the literature with particular regard for academic outcomes. In the present review, in light of our concern for educational relevance, that is what we endeavored to do.

The overarching objective of this review was to derive cross-disciplinary principles about the conceptual and operational nature of relational reasoning that could be used to guide the formation of theoretical models and the conduct of empirical research in the future, as well as potentially influence educational practice. Such a simple statement of overarching intention masks the challenge we faced in unearthing the relevant literature on relational reasoning that was the basis of our systematic analysis; a literature nested within quite varied domains of inquiry (e.g., cognitive science or developmental psychology), where alternative terminology and diverse methodologies were evident. Nonetheless, we regarded this challenge as worthwhile. Through the identification and consolidation of this cross-disciplinary research, we were able to closely examine the included studies with an eye toward identifying any salient definitional and methodological patterns. Only by the identification of these patterns were we able to delve even more deeply in this body of work and to specifically link relational reasoning ability to performance in an academic domain. Coincidentally, we were able to distill guiding principles *about* relational reasoning only by engaging in a manner of relational reasoning. Before we offer the details of our search efforts, overview the findings of this systematic search, and share the resulting relational reasoning principles, we first consider it informative to survey the theoretical roots of the construct of relational reasoning as defined herein.

Conceptual Frame

Relational reasoning has long been regarded as essential to human mental life (e.g., Hofstadter 2001; James 1890; Sternberg 1977). As noted, James (1890) described the ability as fundamental to human thinking and learning, as well as to expert cognitive performance in any domain. Contemporaneously, Gestalt theorists like Wertheimer (1900), whose work posits an ability to grasp the relations between discrete elements as part and parcel with perception, also described a human ability to discern relations.

Later in the twentieth century, in *The Abilities of Man* (1927), Charles Spearman described a model of human cognition largely driven by the ability to “bring to mind any relations that essentially hold” (p. 165) between two ideas or concepts. His belief in the importance of this human cognitive function was so strong that he bemoaned what he saw as the neglect of the *cognition of relations* by his contemporaries. Using an idiomatic analogy, Spearman wrote that this could “only be explained by their not seeing the forest for the trees!” (p. 166). This strong belief in the importance of reasoning by relations carried forward to his students, John Raven and Raymond Cattell, both of whom created tests of intelligence that required individuals to reason with complex relations (Cattell 1940; Raven 1941). Even today, the Raven’s Progressive Matrices (RPM) is a commonly used set of stimuli in empirical research studying relational reasoning (e.g., Baldo et al. 2010). Other researchers in the field of intelligence like Sternberg (1977) also posited an ability to recognize and reason with relations as fundamental to human cognition and argued that individual differences in this ability may be important in explaining differences in intelligence.

Also in the early twentieth century, in his book *Judgment and Reasoning in the Child* (1928/1966), Jean Piaget presented an argument for the centrality of reasoning with relations to cognitive development. His claim that “the fertility of reasoning is due to our unlimited capacity for constructing new relations” (p. 196) was evidence of the crucial role in which he cast this ability. Modern developmentalists like Goswami (1992) pursued inquiries into relational reasoning and described it as a foundational capacity used for early learning in many domains. Specifically, focusing the developmental lens on the ability to attend to and reason with relations has led to fruitful research on topics such as object permanence in infants (Baillargeon and Graber 1987), preschool reading (Goswami and Bryant 1992), the effects of preschoolers’ socioeconomic status (White and Caropreso 1989), and adolescent brain development (Dumontheil et al. 2010).

Cognitive scientists have likewise engaged in the detailed study of relational reasoning. For example, in their now-classic study, Chase and Simon (1973) observed chess masters *chunking* chess pieces using their strategic relations to other pieces on the board. Since that time, cognitive scientists have sought to understand the mechanisms underlying the human ability to recognize and reason with relations (e.g., Gentner 1983). This field has examined these underlying mechanisms by means of diverse methodologies such as computational models (Hummel and Holyoak 2005), brain-imaging (Waltz et al. 1999), text-based studies (Lee and Holyoak 2008), and naturalistic observations (Dunbar 1995). The resulting body of research has led to a greater understanding of how humans reason relationally, as well as the role this construct plays in other mental functions like memory (Kokinov and Petrov 2001) and perception (Mitchell 1993). Hofstadter (2001) describes relational reasoning as essential to all human thought when he depicts it as "the very blue that fills the whole sky of cognition" (p. 499).

Historically, relational reasoning has been described as a singular ability, whose archetypal use was in reasoning with analogies (Goswami 1992; James 1890). Recently however, researchers have suggested that relational reasoning may not be a unitary construct, but that the term may refer to a family of relations that can arise when otherwise disparate information or representations are encountered. For example, Alexander and the Disciplined Reading and Learning Research Laboratory 2012 have suggested that at least four forms of relational reasoning merit further examination: analogy, anomaly, antinomy, and antithesis.

An *analogy* involves the recognition of relational similarity between two seemingly disparate ideas, objects, or events (Hesse 1959). Analogic reasoning has been shown to be a vital ability for experts in scientific domains (Dunbar 2001), as well as instrumental in knowledge transfer (Gentner et al. 2003). Further, the ability to reason by analogy has been empirically connected to learning in many domains including mathematics (Alexander et al. 1997), reading (Goswami and Mead 1992), and science (Braasch and Goldman 2010). Analogical thought may also be essential for understanding language and organizing memory (Hofstadter 2001).

An *anomaly* can be any occurrence or object that is unusual or unexpected—an aberration or digression from an established pattern (Chinn and Brewer 1993). The detection of anomalous sentences has been used for nearly a century as a test for intelligence, especially in children (Binet et al. 1913). It has been shown that attending to anomalies is critical for conceptual change (Chinn and Malhotra 2002) and that it is principally during the process of anomaly resolution that individuals come to understand their own implicit assumptions and logical mistakes (Darden 1995). Some theorists, like Thomas Kuhn (1996), have argued that anomaly detection is the principal way in which science advances. Further, anomalous thinking may be imperative for evaluating inconsistencies while dealing with multiple texts (Afflerbach and Cho 2009).

Another form of relational reasoning, *antinomy*, allows the thinker to understand what something *is* by ascertaining what it *is not*. An antinomy is a paradoxical situation in which a domain of study has come to accept two or more ideas that appear contradictory (Sorensen 2003). By extension, antinomy can also include the ability to reason with mutual exclusivity among categories and recognize and resolve the paradox that arises should they be brought together. That is, the ideas or concepts being related appear incompatible as when theoretical models or conceptual categories are determined to be ontologically distinct (Chi and Roscoe 2002; Opfer and Gelman 2011; Slotta and Chi 2006). For example, as Cole and Wertschb (1996) pointed out, an antinomy can arise when concurrently considering the theoretical arguments of Piaget and Vygotsky. Specifically, the idea that human development can be simultaneously driven by both the individual child and by social processes may involve an antinomy-based paradox. The identification and consideration of antinomies like this one have led to productive discussion and even discovery in fields like mathematics (Russell and

Lackey 1973), reading (Mosenthal 1988), psycholinguistics (Shaumyan 2006), and intelligence (Gardner 1995).

The last of the four forms of relational reasoning presented in this review is *antithesis*, a directly oppositional relation between two mental representations (Kreezer and Dallenbach 1929). The ability to conceptualize antithetical opposition is important for argument and persuasion (Chinn and Anderson 1998; Kuhn and Udell 2007) and conceptual change with refutation text (Broughton et al. 2010). Antithetical relations may also be one of the primary ways in which human language and thought are organized (De Saussure 2011; Kjeldergaard and Higa 1962; Marková 1987).

Despite the long-standing acknowledgment of and the empirical evidence for relational reasoning's importance to students' learning and development, there remain significant questions about the conceptualization and operationalization of relational reasoning forwarded in the extant literature. For instance, it is not yet known whether definitions of relational reasoning need greater specification at the general level, or if the particular manifestations of relational reasoning need to be more fully explicated and their interrelations explored. Further, the perceived need for theoretical and methodological clarity by those interested in the study of relational reasoning—especially given its potential importance in the current educational climate—requires the careful examination of the currently existing cross-disciplinary writing on the construct. For these reasons, we undertook a systematic review of the literature to address these unresolved issues and to address three main research questions:

1. How has relational reasoning been broadly conceptualized and examined in the literature pertaining to human learning and development?
2. How have particular manifestations of relational reasoning (i.e., analogy, anomaly, antinomy, and antithesis) been conceptualized and operationalized in the extant literature?
3. How has relational reasoning been found to relate to academic performance in various educational domains?

Methods

Search Parameters

For this systematic review, all searches for literature were conducted in the PsycInfo database using a title and abstract search and were limited to peer-reviewed publications in the English language. In an effort to address our first research question, we used the specific search terms "relational thinking," which yielded an initial pool 15 total studies, and "relational reasoning," which yielded 54 documents. These searches were not limited by year, which allowed us to be as exhaustive as possible.

In order to address our second research question, we searched for terms representing manifestations of relational reasoning. For these searches, we limited results to the last 5 years (2007–2012). This is because we were specifically interested in the current literature on these forms of relational reasoning. Searches were conducted for the following terms: "analogy" (n=114), "analogical reasoning" (n=41), "anomaly" (n=138), "anomalous" (n=53), "antinomy" (n=2), "ontological categories" (n=2), "refutation" (n=7), "opposite" (n=141), "antithesis" (n=2), and "antithetical" (n=2). These terms were selected based on the manifestations of relational reasoning forwarded in previous theoretical work by Alexander and the Disciplined Reading and Learning Research Laboratory 2012 and were used in an effort to capture empirical publications representing these forms of relational reasoning effectively, even if the authors of these publications did not use language explicitly describing their work as manifestations of the construct.

Inclusion Criteria

Publications were only included if they were empirical, used human subjects, and featured participants engaged in relational reasoning. These criteria excluded non-empirical publications such as theoretical treatises, reviews of the literature, and scholarly rebuttals. Further, these criteria meant that the large subfield that endeavors to examine relational reasoning using computational models was not included in this review (e.g., Morrison et al. 2011; Sebag and Rouveirol 2000; Taylor and Hummel 2009).

Additionally, in order to more closely examine relational reasoning and its manifestations within the field of education, studies were only included if they represented research pertaining to learning and development. This meant that studies representing diverse fields like psychotherapy (e.g., Billow 2003), relationship psychology (e.g., Martin 1991), or marketing and business (e.g., Siddiqi 2012) were not included in the review. This criterion ensured that the lens of our review was firmly focused on those empirical studies that pertained in some way to learning and development, and not on other fields.

Also excluded were studies in which the authors used a relational process to present their findings, but participants' relational reasoning was explicitly not examined. For example, researchers in diverse fields reported finding antithetical or *opposite effects* with two different experimental conditions (e.g., Depino et al. 2011). Further, researchers made analogical references to their findings vis-à-vis what has been established in the literature. Similarly, researchers reported finding anomalies in their own research (e.g., Summers and Duxbury 2012; Walther 2010) or endeavored to discuss antinomies that have arisen in their fields (e.g., Angers 2010). In all these aforementioned cases, however, there was no effort to examine antithetical, analogical, anomalous, or antinomous processing in study participants.

Search Results

Of the initial pool of 571 publications generated by our search terms, 462 were excluded based on the aforementioned criteria, leaving a total of 109 publications to be systematically analyzed for this review. Our final counts for included studies corresponding to each of our search terms were as follows: "relational thinking" (n=2), "relational reasoning" (n=29), "analogy" (n=32), "analogical reasoning" (n=22), "anomaly" (n=11), "anomalous" (n=5), "antinomy" (n=1), "refutation" (n=2), and "opposite" (n=5). Several search terms—"ontological categories," "antithesis," and "antithetical"—did not yield any studies that met the inclusion criteria.

These included studies were organized into two comprehensive tables: one table for studies pertaining to relational reasoning in general and our first research question, and another for studies pertaining to the specific manifestations of relational reasoning and our second research question. Studies in each table (see supplementary material) were analyzed along five central aspects: academic domains examined, definition of the applicable term stated or implied, number and type of participants studied, measures used, and outcomes reported.

Definition Coding Scheme

We first coded all included studies based on whether or not a definition was presented. Only definitions of either relational reasoning or one of the four manifestations of the construct included in this review were considered. Definitions were coded as either (a) explicit or (b) implicit. An article was coded as having an explicit definition if a definition was expressly stated. For example, Kroger et al. (2002) forwarded an explicit definition of relational reasoning as "the ability to represent and integrate complex relationships among stimuli" (p. 477).

Because our inclusion criteria required studies to feature participants reasoning relationally, all included studies necessarily featured some measure or task designed to document relational reasoning. As such, all included studies that did not have an explicit definition implicitly defined the construct by the measure or task that was used to elicit relational reasoning in participants. For example, although she did not explicitly state a definition of anomaly, Filik (2008) implicitly defined the construct with her task: verbal semantic anomalies like "the mouse picked up the dynamite" (p. 1038). Because this stimulus was designed around a conceptualization of anomaly as something unexpected or unusual and given to participants in order to engage them in reasoning with anomalies, the task represented an implicit definition of the construct.

To establish the reliability of our coding scheme, the first and third author coded a subset (17.4 %) of the 109 included studies with a very high level (94.7 %) of exact agreement. For the one case in which the coders disagreed, the discrepancy was resolved through discussion. The first author coded the remaining studies.

Additional Study Classifications

In addition to the definition, academic domain studied, measures used, number and type of participants, and outcomes reported for each of the included studies were determined and entered into the tables. In the table pertaining to particular manifestations of relational reasoning, the form of relational reasoning being examined was also entered into the table. The form of relational reasoning that corresponded to each study was determined based on the search term that yielded the study. For example, because we theoretically identified refutation texts as an instance of antithesis, any studies that were identified by the search term "refutation" (e.g., Broughton and Sinatra 2010) were classified as antithesis in the table.

If a study examined relational reasoning relevant to a specific field of study (e.g., mathematics or biology), that domain was entered into the designated column. Simply examining a particular form of relational reasoning within an academic class or major (e.g., psychology students) did not warrant designation as an academic domain unless the researchers were specifically interested in examining the implications of relational reasoning in the specific domain. If a study linked relational reasoning ability to more than one academic domain, all of the domains were indicated in the table. When no specific domain was deemed relevant, a study was designated as domain general in the table. Any measures or tasks used to engage participants in relational reasoning were entered in the corresponding section of the tables. Similarly, for the participant category, the number and type of participants used in the study were recorded. Any information provided by the author pertaining to the age, grade level, status as disabled, or enrollment in a course of the participants was entered.

The outcome of each study was also entered into the table. Outcomes were only entered into the table if they pertained directly to the construct of relational reasoning. For example, Birney and Halford (2002a) included findings concerning psychometric properties of their measure.

Because these findings did not directly pertain to relational reasoning, they were not entered into the table. Specifically, outcomes were only entered if they pertained to: (a) the physiological processes associated with relational reasoning; (b) group or individual differences in relational reasoning based on age, grade level, status as disabled, or other associated cognitive traits such as fluid intelligence; (c) differences in relational reasoning based on the mode of presentation or contextual frame of the relational stimuli; or (d) performance differences on academic tasks based on individual differences in relational reasoning.

Results and Discussion

Relational Reasoning in General

Our first research question concerned the way in which relational reasoning in general has been conceptualized and examined in the literature pertaining to human learning and development. The literature analyzed in the effort to answer this question was found using the search terms "relational thinking" and "relational reasoning" because here we are interested in publications examining relational reasoning itself as a general construct, and not its specific manifestations. Findings of the included studies are summarized according to the following six aspects: (a) domain specificity, (b) definitions and conceptualizations of relational reasoning, (c) measures used, (d) methodologies and (e) participants, and (f) domain-general outcomes.

Domain Specificity

The current literature on relational reasoning in general is dominated by research examining the construct outside of any academic domain. Of the 31 studies that pertained to relational reasoning in general, only a small fraction (9.6 %) of studies examined relational reasoning in a way that pertained to a specific academic domain. Of those studies that were classified as domain specific, 66 % examined relational reasoning in the domain of mathematics and 33 % in the domain of biology.

Definitions and Conceptualizations

Within the general relational reasoning literature, there were two trends in the conceptualization and definition of the core construct. The first pertained to the conceptualization of relational reasoning in terms of deductive reasoning, and the second dealt with the characteristics of construct definitions.

Deductive vis-à-vis Relational Reasoning When examining the 31 studies relevant to this category, a distinction emerged between two contrasting conceptualizations of the construct. Specifically, the majority of reviewed studies (67.7 %) conceptualized relational reasoning similarly to what was presented in the conceptual framing of this review, that is, as an ability to attend to and reason about multiple relations between mental representations (Crone et al. 2009; Krawczyk et al. 2011). In contrast, a subset of the examined studies (32.3 %) defined relational reasoning as a specific kind of deductive reasoning in which given premises are relational in nature (e.g., Acredolo and Horobin 1987; Prado et al. 2010). For example, Acredolo and Horobin (1987) defined relational reasoning as "deductive reasoning about the relations between objects" (p. 1). This definition of relational reasoning can be operationalized by the following problem posed by Van der Henst and Schaeken (2005, p.1):

A is to the left of B
B is to the left of C
D is in front of A
E is in front of C

What is the relation between D and E?

This frequent characterization of relational reasoning as a form of deductive reasoning is a conceptualization that pertains more precisely to reasoning about the physical positioning of some object or symbol in relation to another, or about the ordering of objects based on some specified property (Munnelly et al. 2010). As our interest in learning and development seems to necessitate and as the conceptual frame presented in the beginning of this review suggests, our interest in relational reasoning stems from its potential to be broadly applicable and widely used by learners. Thus, while we do not argue that deductive reasoning as represented in the review studies is a specific case of relational reasoning, we do not regard it as equivalent to the general construct.

Despite the fact that relational–deductive reasoning has a long history with the oldest representative publication being Morgan and Carrington's 1944 study, the broader conceptualization has an even longer history reaching back at least to William James. The only study we found that used both types of conceptualizations simultaneously was by Waltz et al. (1999). However, the principal focus of their study was the role that the prefrontal cortex plays in the integration of relational complexity, and not the differences or similarities between the two conceptualizations. The variable of relational complexity was operationalized from both a relational–deductive task and a task frequently used by those who conceptualize the construct more broadly (i.e., the Raven's Progressive Matrices) by counting the number of relations that a participant would have to consider to correctly solve the problem. This methodology allowed Waltz and colleagues to quantify relational complexity across the different types of tasks, but did not facilitate a comparison between the different relations found in each. The results of Waltz et al. (1999) showed that as relational complexity increases, so does task difficulty for both types of tasks. The researchers also showed that patients with damage to the prefrontal area of the brain had a much steeper fall in accuracy on both tasks as relational complexity increased then healthy controls. Thus, their results may suggest that these two conceptualizations of relational reasoning are, as we contend, associated.

It is important to state that we recognize the significance of the recent research on deductive reasoning, especially given the strides that this field has made in uncovering how complex thought happens in the brain (e.g., Mason et al. 2010). Nonetheless, for the remainder of this review, findings and discussion will incorporate only those publications that define relational reasoning in the broader sense as pertaining to recognizing and deriving meaningful relations between multiple mental representations.

Characteristics of Definitions Among these 21 publications examining relational reasoning in general, there was a lack of explicit definitions. Most of the included studies (61.9 %) defined the construct of relational reasoning implicitly (e.g., Baldo et al. 2010; Scruggs et al. 1994), with a minority (38.1 %) explicitly stating a definition (e.g., Crone et al. 2009). Notably, those studies that defined the construct implicitly used a wide variety of measures and tasks to do so. The measure that was most relied upon to implicitly define relational reasoning in the included studies was

RPM. However, only 23.1 % of those studies coded as implicit utilized the RPM. The diversity of measures used in the literature pertaining to relational reasoning in general is further explicated in the measures section of this review.

All of the definitions of relational reasoning put forth in these included studies—whether implicit or explicit—posited a broadly applicable ability to consider relations between concepts. Because of this, the current conceptualization of relational reasoning found in the literature seems to be compatible with the foundational ability that theorists like James and Spearman first described. For example, Crone et al. (2009) defined relational reasoning broadly as "the ability to consider relationships between multiple mental representations" (p. 55). As with the definitions of James and Spearman, this conceptualization portrays relational reasoning as a potentially fundamental construct with wide-ranging implications. Based on our analysis of the general definitions of relational reasoning populating the literature, we offer a summary definition of this general construct in Table 1, along with literature-derived definitions for more particular manifestations of relational reasoning.

Further, the wide applicability of this conceptualization seems to support the argument forwarded by Alexander and the Disciplined Reading and Learning Research Laboratory 2012 that relational reasoning may not be a unitary construct, but may refer to a variety of relations that can be identified between pieces of otherwise discrete information. This work suggests that at least four forms of relational reasoning may be important for further study: analogy, anomaly, antinomy, and antithesis.

Table 1 Literature-based definitions for relational reasoning and its manifestations

General construct/Particular form	Definition	Example citations
Relational reasoning	The ability to discern meaningful patterns within otherwise unconnected information	Alexander and the Disciplined Reading and Learning Research Laboratory 2012; Crone et al. 2009; Holyoak 2012; Krawczyk et al. 2011
Analogy	The identification of a structural similarity between two or more concepts, objects, or situations	Bostrom 2008; Trey and Khan 2008; Leech et al. 2007; Watson and Chatterjee 2012
Anomaly	The ability to discern an abnormality, digression, or deviation from an established pattern	Ferguson and Sanford 2008; Filik and Leuthold 2008; Schulz et al. 2008; Trickett et al. 2009
Antinomy	The ability to recognize incompatibilities or paradoxes within an informational stream	Cole and Wertschb 1996; Gardner 1995; Mosenthal 1988; Russell and Lackey 1973; Shaumyan 2006; Sorensen 2003
Antithesis	The identification of a directly oppositional relation between two ideas, concepts, or objects	Baker, et al. 2010; Bianchi et al. 2011a, b; Heit and Nicholson 2010

Measures

Our analysis of the empirical literature dealing generically with relational reasoning revealed a noticeable mismatch between conceptualization and operationalization. That is to say, despite its broad conceptualization, relational reasoning was often operationalized narrowly. More to the point, many of the articles we examined tended to operationalize the construct solely by means of a measure of analogical thinking and most often via one commonly used instrument. Specifically, 33 % of the 21 included studies in this portion of the review utilized the RPM (e.g., Eslinger et al. 2009; Baldo et al. 2010) or some instrument for which researcher-developed items closely resembled the RPM (e.g., Krawczyk et al. 2011).

One possible reason for the aforementioned pattern is that alternative measures with adequate psychometric properties may not be readily available to those invested in the study of relational reasoning. The creator of the RPM, John Raven, was a student of Charles Spearman. Like his mentor, Raven argued for the centrality of relational reasoning to human intelligence. However, Raven's instrument has come to be seen as wholly analogical in nature (Bunge et al. 2005). Although research using the RPM has been fruitful for the field, an over reliance raises several concerns. For one, it constrains the measurement of the broad construct of relational reasoning to one particular manifestation (i.e., analogy). Further, there is the issue of separating the construct of relational reasoning from fluid intelligence and general cognitive function—the trait which the RPM is currently marketed and widely used in clinical settings to assess (e.g., Warren et al. 2004).

Other commonly used measures in this literature include relational match-to-sample tasks (used by 9.5 % of the 21 included studies) where participants are asked to identify a given pattern and then select its analog (Son et al. 2011), verbal four-term analogies in the form of A:B::C:D (14.3 %; e.g., Wendelken et al. 2008) and four-term pictorial analogies, also in the form A:B::C:D (23.8 %; e.g., Krawczyk et al. 2008). Each of these tasks is different from the RPM, but they all share the same focus on analogy as the form of relational reasoning being tested.

Methodology

More than half (57.1 %) of the 21 included studies came from a cognitive neuroscience paradigm (e.g., Kroger et al. 2002; Wendelken et al. 2008) and, as such, used neuroscientific methods, especially functional magnetic resonance imaging (fMRI), to examine relational reasoning in participants. This large body of work means that much is known about the cortical substrate of relational reasoning (for a review of these findings, see Krawczyk 2012). However, although brain imaging was the most common methodology used in this body of literature, there were studies incorporating methodologies closer to the educational context. These include research conducted in schools (e.g., Farrington-Flint et al. 2007; Son et al. 2011), in which relational reasoning ability was empirically connected to educational outcomes and inferences were made about the best way to promote learners' relational reasoning. Other methodologies present in this literature included cognitive tasks and measures given in a laboratory setting (e.g., Birney and Halford 2002b) and semi-structured interviews (Stephens 2006).

Participants

One apparent strength of the literature on generic relational reasoning is the many different populations that have been studied. The construct of relational reasoning has been examined in preschoolers (Son et al. 2011), elementary-school students (Crone et al. 2009), adolescents (Eslinger et al. 2009), students with intellectual disability (Scruggs et al. 1994), healthy adults (Krawczyk et al. 2011), men with Klinefelter's syndrome (Fales et al. 2003), patients with brain injuries (Waltz et al. 1999), and stroke patients (Baldo et al. 2010). This diversity of samples can allow the field to make inferences on the development of this construct, as well as the ways that particular students may struggle with relational reasoning tasks based on their age and neurological condition.

Domain-General Outcomes

While those outcomes reported in the literature pertaining to relational reasoning in general that concerned a specific academic domain are examined in a later section of this review, outcomes concerning relational reasoning outside of any particular academic domain are discussed here. Because much of the research on relational reasoning in general has been conducted using neuroscientific methodologies, many of the outcomes reported center around the neural activation and brain physiology that is associated with the construct. For example, Krawczyk et al. (2008) found that intact pre-frontal cortex is necessary for participants to achieve a high level of accuracy on a relational reasoning task. Further, some studies reported findings that were both physiological and developmental in nature. For instance, the results of Crone et al. (2009) indicated that the development of rostrolateral prefrontal cortex is specifically implicated in children's emerging ability to reason relationally. Reported outcomes such as this suggest that neuroscientific methods may be useful for answering questions about the development of relational reasoning ability in children and adolescents.

Also present in the included literature were findings concerning the properties of relational reasoning tasks, especially the elements of the task to which task-difficulty can be attributed. Studies that presented these findings generally focused on elements of tasks like relational complexity (Birney et al. 2006; Waltz et al. 1999) or the salience of distracters (Krawczyk et al. 2008). By specifically examining the elements of a task that contribute to task-difficulty, these studies may allow the field to make more specific inferences about the source of variability in participants when reasoning relationally.

Although the research on generic relational reasoning provides an important window into the role that the construct plays in learning and development, the picture may be incomplete until the research on the particular manifestations of relational reasoning (i.e., analogy, anomaly, antinomy, and antithesis) are incorporated. This larger body of research—when brought together—brings to bear much more knowledge about relational reasoning and its importance in learning and development.

Particular Manifestations of Relational Reasoning

Our second research question for this review concerns the way in which the particular manifestations of relational reasoning (i.e., analogy, anomaly, antinomy, and antithesis) have been conceptualized and operationalized in the extant literature pertaining to human learning and development. Because the literature analyzed to answer this second research question was procured using search terms that theoretically corresponded to each particular form of relational reasoning, the findings in this section of the review will be presented as corresponding to the form of relational reasoning the search terms represent. Similar to relational reasoning in general, findings about this literature are analyzed around six aspects of the included studies: (a) domain specificity, (b) definitions and conceptualizations, (c) measures used, (d), participants, (e) methodologies, and (f) domain-general outcomes. Within the sections for each of the particular manifestations of relational reasoning, findings are organized under these six headings.

Analogy

The first form of relational reasoning analyzed in this review is analogy. The literature about this form of relational reasoning was identified using the search terms "analogy" and "analogical reasoning."

Domain Specificity Of the 54 studies that pertained to analogy, the majority (70.4 %) examined the construct in a domain general way. This high proportion of studies classified as domain general suggests that the bulk of research conducted on analogical reasoning is concerned with the construct as it operates outside of any specified domain. A minority (29.6 %) of the included studies examined analogical reasoning in a particular domain. However, domain specificity exists in a much larger proportion in the literature pertaining to analogy than it does for relational reasoning in general. Of those studies classified as domain specific, 12.5 % examined analogy in the domain of chemistry, 18.8 % in physics, and 6.3 % in meteorology. Combined, 37.5 % of the domain-specific studies examined analogy in a scientific domain. Further, 25 % examined analogy in the domain of reading, 12.5 % in the domain of writing, and 31.25 % in the domain of mathematics. These findings suggest that the interest in domain specific inquiry on analogical reasoning is not limited to one or two domains, but rather to a variety of domains in which analogical reasoning may play a role.

Some of the included publications presented domain-specific findings pertaining to more than one academic domain; these studies were included in the proportions for each of their domains. A total of 12.5 % of the studies classified as domain specific featured two domains of interest. For example, Klein et al. (2007) examined the role of analogical reasoning both in students writing and in their understanding of physics concepts. This study is represented in both the proportion of studies featuring the domain of writing and the proportion of studies featuring the domain of physics.

Definitions and Conceptualizations In contrast to what was found in the literature pertaining to relational reasoning in general, the majority (57.4 %) of the 54 studies pertaining to analogy featured an explicit definition (e.g., Ball et al. 2010; Cho et al. 2010; Thibaut et al. 2010). The literature on analogy also differed from the literature on relational reasoning in general in that, while the literature on relational reasoning in general contained a rift between competing conceptualizations of the construct, the literature pertaining to analogy shared a common definitional focus. Indeed, all of the included studies on analogy forwarded a definition—implicit or explicit—that emphasized the identification of a deep structural similarity between two or more concepts, objects, or situations (e.g., Bostrom 2008; Trey and Khan 2008). For example, Leech et al. (2007) defined analogical reasoning as an ability to judge "the similarity between relations and structures of relations" (p. 897). At the same time, Watson and Chatterjee (2012) argue that, "two objects, concepts, or even real-world situations are analogous if they are dissimilar on the surface but share some higher-order structural similarities" (p. 2831).

As is apparent across these two quotes, a conceptualization of analogical reasoning as the recognition of and reasoning with the relation of similarity is a common thread that binds the literature together. Nonetheless, the field is full of investigations into different kinds of similarity. For example, some of the included studies focused on similarity based on category membership (e.g., Green et al. 2008), others focused on the similarity of physical processes (e.g., Braasch and Goldman 2010), and still others focused on perceptual or visual similarity (e.g., Holliway 2007). Although these diverse conceptualizations of the relation of similarity are qualitatively different in their approach, this does not necessarily create a problem for the classification of each as analogy. This is because an analogy is not defined by the aspects of ideas that are similar, but rather by the presence of similarity itself (Goswami 1992).

This relatively broad conceptualization of what constitutes an analogy has enabled the field to identify this form of relational reasoning at work in some perhaps unexpected places. For instance, an important minority of included studies framed two forms of morphological similarity between words—rime (e.g., *spoil* and *boil*) and rhyme (e.g., *light* and *bite*)—as analogies (e.g., Schiff and Ravid 2007). This identification of these two forms of morphological similarity as analogy has shed light on the way these forms of similarity are used in beginning reading (e.g., Farrington-Flint and Wood 2007).

Measures The most commonly used measures in the literature pertaining to analogy are verbal or pictorial four-term analogies in the form of A:B::C:D (e.g., Maguire et al. 2012; Tzuriel 2007). A significant proportion (40.7 %) of the 54 included studies incorporated this kind of task. This prevalence of four-term analogies probably reflects the historic popularity of this form, as well the relative ease with which they can be created and presented to participants. However, other forms of analogy were also present in the literature. These forms included scene analogies (e.g., Gordon and Moser 2007) in which participants were asked to identify analogous elements between two illustrated scenarios, visual–spatial analogies similar to Raven's Progressive Matrices (e.g., Tunteler and Resing 2010), analogies presented in text (e.g., Braasch and Goldman 2010; Leech et al. 2007), and analogies in student writing (Holliway 2007).

Methodologies In contrast to the literature pertaining to relational reasoning in general—which leaned heavily on neuroscientific methodologies—there was no single dominant methodology present in the literature on analogy. The methodologies in this literature included eye-tracking (e.g., Vakil et al. 2011), brain-imaging (e.g., Volle et al. 2010; Krawczyk et al. 2010, 2011), semi-structured interviews (e.g., Bostrom 2008), large-scale psychometric studies (e.g., Ullstadius et al. 2008), classroom intervention (e.g., Tzuriel and George 2009), and think alouds (e.g., Braasch and Goldman 2010).

Participants The body of literature pertaining to analogy also encompasses an impressive diversity of participants. In the past 5 years, analogical reasoning has been studied in patients with brain damage (e.g., Schmidt et al. 2012), students with intellectual disability (e.g., Denaes 2012; Vakil et al. 2011), children with autism (e.g., Morsanyi and Holyoak 2010), preschoolers (e.g., Stevenson et al. 2011), elementary school students (e.g., Savage et al. 2011), adolescents (e.g., Bellocchi and Ritchie 2011), undergraduates (e.g., Braasch and Goldman 2010), preservice teachers (e.g., James and Scharmann 2007), active duty soldiers (e.g., Ullstadius et al. 2008), and students with specific language impairment (e.g., Leroy et al. 2012), among others.

Domain-General Outcomes Because of the diversity of methodologies represented in the research pertaining to analogical reasoning, there are a wide variety of domain-general findings reported in this literature. The included studies present findings concerned with neural activation and brain physiology (e.g., Volle et al. 2010), the mode of presentation of an analogical task (e.g., Stevenson et al. 2011), differences in analogical reasoning based on age or status as disabled (e.g., Schiff and Ravid 2007), accounts of cognitive systems that explain participants' processing of analogies (e.g., Green et al. 2008), psychometric data of analogical reasoning assessments (e.g., Ullstadius et al. 2008), and differences in the cognitive processing of analogies based on the relations present (e.g., Green et al. 2012).

For example, the results of Volle et al. (2010) suggest that the dorsomedial sub-region of rostrolateral pre-frontal cortex is specifically active during the initial mapping stages of analogical reasoning, further explicating the neural substrate of relational thought. Stevenson et al. (2011) found no significant differences in participants' performance across paper or computer presentation conditions of analogy tasks, alleviating any qualms in the field about presenting measures on a computer screen. Schiff and Ravid (2007) found that adult dyslexics performed similarly to typically developing third grade students on a morphological analogies task, providing a new lens on the reading deficit associated with dyslexia. Green et al. (2008) argue that four-term analogies are processed in the mind through the activation of micro-categories associated with each of the terms, using data to support their theoretical position. Ullstadius et al. (2008) present a factor analysis of an analogical reasoning measure, allowing the field to further understand the distinctions between sets of analogies based on their terms. Green et al. (2012) show that the greater the semantic distance between the terms in a four-term analogy, the greater the frontopolar cortex activation required to correctly solve the analogy, suggesting that semantic distance between terms of comparison may be associated with the difficulty of analogical reasoning in a given situation.

Anomaly

The second manifestation of relational reasoning to be examined in this review is anomaly. The literature analyzed here was produced using the search terms "anomaly" and "anomalous."

Domain Specificity Of the 16 studies pertaining to anomaly, 56.3 % examined the construct in a domain-general way, while 43.7 % studied anomaly in a specific academic domain. Of the four manifestations of relational reasoning reviewed, this represented the highest proportion of domain specificity. Of the studies classified as domain-specific, 71.4 % examined anomaly in the domain of reading, 14.2 % in meteorology, and 14.2 % in mathematics.

Definitions and Conceptualizations There was a lack of explicit definitions in the literature pertaining to anomaly. Specifically, only a quarter (25 %) of the 16 studies featured an explicit definition. The remainder (75 %) defined the construct implicitly through their use of certain measures and tasks (e.g., Mishra et al. 2011; Sanford et al. 2011). However, all explicit and implicit definitions coalesced around the idea of anomaly as an ability to attend to and reason with something unusual, unexpected, or that digresses from an established pattern (e.g., Schulz et al. 2008).

For example, Trickett et al. (2009) defined an anomaly as "any phenomenon that deviates from a common form, that displays inconsistency with what is expected, or that is generally considered 'odd' or 'peculiar' in some way" (p. 711). This definition of anomaly speaks to the importance not only of the unanticipated nature of the anomaly itself but also to the context in which the anomaly is presented. Because an anomaly is something unusual or unexpected, what *is* usual or expected becomes vital to its definition. Consequently, the literature on anomaly contains a subset of studies specifically concerned with manipulating the context in which an anomaly is presented, in an effort to negate its status as an anomaly, and turn it into something expected and quotidian (e.g., Ferguson and Sanford 2008; Filik and Leuthold 2008).

Measures Half (50 %) of the 16 studies used verbal semantic anomalies as their principal measure (e.g., Faustmann et al. 2007; Filik 2008; Weber and Lavric 2008). Verbal semantic anomalies are short passages or sentences that contain unusual information. For example, this short passage, taken from Filik and Leuthold (2008), can be presented as nonanomalous:

> Terry was very annoyed at the traffic jam on his way to work.
> He glared at the [truck] and carried on down the road.

Or anomalous:

> Terry was very annoyed at the traffic jam on his way to work.
> He picked up the [truck] and carried on down the road.

It can also be presented in a fictional context, negating the anomaly:

> The Incredible Hulk was annoyed that there was a lot of traffic in his way.
> He picked up the [truck] and carried on down the road.

Verbal semantic anomalies that describe something unusual, unexpected, or, in this case, physically impossible are far and away the most widely used measure in the literature pertaining to anomaly. This popularity of verbal semantic anomalies dates back to Binet et al. (1913), who used a child's ability to identify anomalies in *absurd phrases* as a test of intelligence.

However, other measures were also utilized. These include mathematical problems solved incorrectly (Chen et al. 2007), inconsistent information presented in narrative texts (Stewart et al. 2009), and video of impossible human movements (Kosugi et al. 2009).

Methodologies Similar to the literature pertaining to relational reasoning in general, the literature analyzed here leaned heavily on neuroscientific methods, with a significant proportion (43.7 %) of the 16 studies incorporating either event-related potentials (ERP; e.g., Sanford et al. 2011; Vissers et al. 2010) or fMRI (Ahrens et al. 2007). This emphasis on neuroscientific methods, especially the use of ERP, could have to do with the predicable effect—the N400—that is elicited by verbal semantic anomalies in ERP studies. The N400 effect refers to a potential in the negative direction, observed approximated 400 ms after the stimulus onset, that is closely associated with anomaly. This clear denotation of an anomaly by the N400 effect has enabled researchers to closely study how people reason with verbal semantic anomalies and, as has already been discussed, how altering the context of the phrase can negate the anomaly and the N400 effect that goes with it.

However, other methodologies are also used to make this form of relational reasoning evident in participants. For instance, eye tracking (e.g., Bohan and Sanford 2008) can operate much the same way as ERP in that it allows researchers to observe when participants identify the unexpected information in a verbal semantic anomaly. As another way to denote a participant's noticing of an anomaly, read time can also be used, especially for studies incorporating slightly longer anomalous passages (e.g., Stewart et al. 2009). A major strength of each of these methodologies is that they do not rely on participants themselves to report the existence of an anomaly, but are able to tap the consequences (i.e., N400, eye-gaze patterns, and extended read time) of an anomaly being present in stimuli. This may allow researchers to observe processes in the resolution of an anomaly that operate below the level of consciousness.

Further, researchers like Trickett et al. (2009) have used naturalistic observation of scientific experts to explain how anomalies are attended to and resolved by professional scientists. This naturalistic observation method, termed in vivo research, was first popularized by Dunbar (1995) and has been shown to be effective at capturing relational reasoning happening in the minds of scientists.

Participants In contrast to the bodies of literature pertaining to either relational reasoning in general or analogy, the research on anomaly relied heavily on the use of undergraduate students as participants. Three quarters (75 %) of the 16 studies used undergraduates (e.g., Bohan and Sanford 2008; Chen et al. 2007; Sanford et al. 2011). However, there are some publications in this body of literature that do incorporate participants other than undergraduates. For example, studies have been done with intellectually disabled adults (Chang et al. 2012), expert scientists (Trickett et al. 2009), older adults (Faustmann et al. 2007), bilinguals (Weber and Lavric 2008), infants (Kosugi et al. 2009), and preschoolers (Schulz et al. 2008).

Domain-General Outcomes The domain-general outcomes reported in the included studies that pertained to anomaly included differences in cognitive processing of anomalies based on the context in which the anomaly is presented (e.g., Filik and Leuthold 2008), the role of affect in the processing of anomalies (e.g., Vissers et al. 2010), and reasoning with anomalies across the lifespan (Faustmann et al. 2007). For example, Filik and Leuthold (2008) found that presenting a verbal semantic anomaly in a fictional context could negate the N400 effect associated with the recognition of something anomalous, showing that the categorization of a given stimulus as an anomaly crucially depends not only on its status as unexpected but also on what, in a given context, is expected. Vissers et al. (2010) observed that the ERP effect for reasoning with an anomaly was different for participants who had just watched a happy film clip than for those who watched a sad one, showing that mood can interact with cognitive processes during the resolution of anomalies. Faustmann et al. (2007) found that age did not significantly affect the strength of the N400 effect for their sample of older adults in their 1950s, 1960s, and 1970s, providing evidence for the idea that the ability to attend to anomalies remains generally intact in older populations.

Antinomy

The third form of relational reasoning to be analyzed in this review is antinomy. Empirical publications studying participants' reasoning with antinomies were sought with the search terms "antinomy," "antinomous," and "ontological categories." The first two search terms were chosen in the same way as the terms in our previous two searches. They are forms of the word used to represent this particular manifestation of relational reasoning. However, because of the extreme paucity of studies yielded by searches for these two terms, we expanded our search and chose the third term on a theoretical basis.

Because an antinomy necessitates a paradoxical situation where two mutually exclusive categories have been brought together (Gardner 1995; Sorensen 2003) and ontological categories are metaphysical classes of being in which all entities can be organized (Chi and Slotta 1993), we hypothesize that antinomies may arise with some frequency as learners grapple with the ontology of certain incompatible ideas and concepts. Further, previous research incorporating ontological categories (e.g., Slotta and Chi 2006) suggests that these classifications may be important for learning and conceptual change. This prompted us to include the term "ontological categories" with the hope that it would yield empirical research pertaining to learning in which participants are engaged in reasoning with antinomies. Unfortunately, this was not the case.

All told, only one study representing antinomy met the criteria for inclusion in this review. This single study by Tanca et al. (2010) focused on strategies used by participants to resolve perceptual antinomies. These perceptual antinomies involved visual illusions formed by the specific placement of color and line in a figure. Although these perceptual antinomies differ from the more conceptual antinomies that are likely of greater importance for human learning and development, the strategies used by participants to resolve them may speak to strategies that students could use to resolve an antinomy between two or more conceptual categories they encounter in a learning environment. For example, Tanca et al. argued that participants resolve perceptual antinomies through a process of visually deconstructing the figure into component parts and then, when the properties of these components have been discerned, reconnecting the components into a whole. Indeed, this process seems to parallel the way in which conceptual antinomies recognized by scholars in a given field are resolved. In these publications (e.g., Cole and Wertschb 1996; Matte-Blanco 1988; Mosenthal 1988), we observe scholars attempting to resolve antinomies through a process of first attending to the antinomy in a broad sense and then carefully deconstructing its elements and conceptually resituating them in the larger argument. Finally, when the antinomy has been resolved, the concept that was, at the outset, logically undermined by a paradox is reconstructed so as to make reasonable sense.

While it is apparent that participants' ability to reason with antinomies is understudied in the field, it is nonetheless an important topic for examination for two reasons. First, the literature does include instances of experts reasoning by antinomy (e.g., Angers 2010), and the ability to deal with seeming incompatibilities or paradoxes has been shown to be basic to conceptual development in classification-based sciences (Opfer and Gelman 2011; Slotta and Chi 2006). Such trends suggest that antinomous reasoning may play an essential, albeit it understudied, role in the development of expertise. Second, the limited body of research on antinomy, in the face of growing interest in relational reasoning more generally, begs the question as to whether it is an opportune time to raise awareness about this particular form of relational reasoning as a catalyst for further study.

Antithesis

The final manifestation of relational reasoning examined in this review is antithesis. The literature about this form of relational reasoning was identified using the search terms "antithesis," "antithetical," "opposite," and "refutation." The first two search terms were used because they are forms of the term used to represent this manifestation of relational reasoning, while the third was used because it is an often-used synonym for the first. The fourth search term was chosen on a theoretical basis. Specifically, because an antithesis involves a relation of direct opposition (Kreezer and Dallenbach 1929), we hypothesized that the task of directly refuting a given concept may be an important application of antithetical reasoning in the learning context.

Domain Specificity Of the seven included studies that pertained to antithesis, 71.4 % examined the construct in a domain-general way and 28.6 % examined the construct in a specific academic domain. Of the studies classified as domain-specific, all of them involved two domains. Specifically, all featured the domain of reading due to the use of refutation text, and within those text-based studies, 50 % dealt with the domain of astronomy and 50 % the domain of physics. These proportions are not additive because each study that incorporated two domains is included in the proportion corresponding to both of those domains. For example, Diakidoy et al. (2011) featured students reading a text designed to refute misconceptions in the domain of physics. Thus, this study is included in the proportions for both the reading and the physics domains.

Definitions and Conceptualizations None of the seven included publications in this analysis featured an explicit definition of antithesis. However, all of the implicit definitions present in this body of literature forwarded a conceptualization of antithesis as a directly oppositional relationship between two ideas or objects (e.g., Baker et al. 2010; Bianchi et al. 2011b).

This agreement by the field means that there are no competing conceptualizations of what antithetical reasoning could be, as there was with relational reasoning in general. So, divergence in this body of literature comes mainly from other aspects of the studies, such as measures used to elicit antithetical reasoning.

Measures The most common stimulus used in these publications to make participants engage in antithetical reasoning was verbal opposites like "tall" and "short" which participants place on scales of polarity (e.g., Bianchi et al. 2011a). The use of such tasks allowed researchers to make inferences about the way that the relation of opposition is used to organize our language and our thoughts (Bianchi et al. 2011b). Interestingly, in a publication by Baker et al. (2010), verbal opposites were incorporated into the design of a card game that was used to test the antithetical reasoning ability of children of different ages. This illustrates the potential use of verbal opposites to answer developmental questions.

While 71.4 % of the seven included studies used these verbal opposites, some studies also used refutation texts designed to directly counter scientific misconceptions (e.g., Broughton and Sinatra 2010), as well as semi-structured interviews concerning the oppositional nature of everyday concepts (Fischer et al. 2008).

Methodologies Those studies included in this analysis that used refutation texts as their principle measure also used a reading based methodology in which students read the refutation text itself, as well as a control—usually an expository text of the kind often encountered by students in science classrooms (Broughton and Sinatra 2010). This research paradigm may be able to be conceptualized as a comparison between a refutation text that is designed to directly support relational reasoning and an expository text that is not. Sinatra and Broughton (2011) offer a recent review of the findings of this interesting line of research.

Apart from these studies and the semi-structured interviews already described, the principal methodology utilized by this literature was the use of questionnaires concerning the oppositional nature of different words or concepts (e.g., Bianchi et al. 2011a; Heit and Nicholson 2010).

Participants The majority (71.4 %) of the seven studies in this section used undergraduate students as participants (e.g., Diakidoy et al. 2011; Heit and Nicholson 2010). However, some participants drawn from populations other than undergraduate students were also present in this literature, namely preschoolers (Baker et al. 2010) and older adults (Fischer et al. 2008).

Domain-General Outcomes The domain-general findings presented in the literature pertaining to antithesis included investigations into the polarity of opposites (e.g., Bianchi et al. 2011b) and age-related differences in antithetical thinking (Baker et al. 2010; Fischer et al. 2008). For example, Bianchi et al. (2011b) found that their participants conceptualized a variety of types of opposites, suggesting that these multiple instances of opposition may support the idea that antithetical thinking is fundamental in the organization of human language and thought. In their investigation of age-related differences in antithetical thinking, Baker et al. (2010) found a steep developmental trajectory in the ability to conceptualize opposites between the ages of 3 and 5. On the opposite end of the lifespan, Fischer et al. (2008) observed that an awareness of antitheses continues to be highly prevalent in human thought after the age of 80.

Academic Outcomes

The third and final research question in this review concerns the domain-specific educational outcomes to which relational reasoning has been empirically linked. To answer this question, we treated all of the studies included in this review as one body of literature. That is, all of the included publications representing particular manifestations of relational reasoning as well as that on relational reasoning in general were combined and taken to signify a broadly conceptualized construct of relational reasoning ability in diverse contexts. Then, this literature was organized around the academic domain empirically linked to relational reasoning ability.

This decision to target domain-specific studies of relational reasoning was predicated on our goal to identify and examine those studies that linked relational reasoning ability to academic success in a particular educational context. The targeting of domain-specific studies meant that many studies included in the review were not featured in this particular analysis. For example, most publications from the field of cognitive neuroscience—despite the importance of their findings in our understanding of the neural and cognitive mechanisms of relational reasoning—were not featured here.

About a quarter (25.7 %) of the 109 studies included in this review empirically linked relational reasoning ability to success in a particular academic domain. Of these studies, 7.1 % examined relational reasoning in the domain of astronomy, 3.5 % in biology, 14.3 % in physics, 7.1 % in chemistry, and 7.1 % in meteorology. Combined, 39.1 % of the domain-specific studies examined relational reasoning in a scientific domain. Further, 28.6 % of the studies linked relational reasoning ability to the domain of mathematics, 39.3 % to reading, and 7.1 % to writing. Because some studies examined relational reasoning ability in two academic domains and these studies are included in the percentages corresponding to both of those domains, the percentages presented above are not additive. In elaborating further on the educational outcomes of this research, we organize discussion around the broadly conceived academic domains of mathematics, science, reading, and writing.

Mathematics

The studies that linked relational reasoning to mathematics learning or achievement focused on a variety of different aspects of the domain, including the correlated development of relational reasoning and mathematical ability (Farrington-Flint et al. 2007), the importance of mathematics instruction that incorporates relational reasoning (Tzuriel and George 2009), and cultural differences in cognitive supports provided for students engaging in relational mathematics learning (Richland et al. 2007). This suggests that relational reasoning ability has been empirically linked to diverse aspects of students' mathematics learning and achievement.

For example, in their study, Farrington-Flint et al. (2007) found that the development of relational reasoning ability was an important contributor to elementary school students' ability to solve addition problems. This implies that relational reasoning ability may play a role in early mathematical operations. Indeed, Tzuriel and George (2009) found that third-grade students who took part in a classroom intervention designed to improve their relational reasoning had significantly higher mathematics ability than a control group at post test. This study utilized a standardized mathematics test that included addition, subtraction, some multiplication, and other early mathematical concepts, showing that relational reasoning ability may be fundamental for achievement in a variety of early mathematical operations.

In a related study, Tzuriel and Shamir (2010) found that third-grade peer-tutors trained to teach kindergartners how to solve a relational reasoning task as well as mathematic problems showed significantly more improvement on mathematics ability than a control group who only worked on mathematics. Interestingly, these effects were found for both the tutors and the tutees, suggesting that relational reasoning ability is important for mathematics even at the kindergarten level. These findings also imply that relational reasoning may be a powerful instructional tool as well as a useful learning strategy.

In an inquiry about the role of relational reasoning in mathematical pedagogy, Richland et al. (2007) analyzed videotaped instruction gathered through the Trends in International Mathematics and Science Study (TIMSS). In their study, they coded the video for the cognitive support that mathematics teachers in Hong Kong, Japan, and the USA gave to relational learning. Their findings revealed that, while American teachers presented a comparable amount of relational instances as their Asian counterparts, they offered significantly less cognitive support to help students reason through those situations. By presenting this finding as a partial explanation for the US' low score on the TIMMS as compared to Hong Kong and Japan, Richland and her colleagues pointed to a possibly fruitful paradigm in the study of relational reasoning: one where instructional support for relational reasoning, rather than the reasoning per se, is the focus of the investigation.

In a follow-up study, Richland et al. (2010) found Chinese preschoolers outperform their American counterparts on a relational reasoning task even when they both have adequate knowledge of the relations at hand. Richland and colleagues point to executive functioning and a lack of explicit cognitive support for relational reasoning in the classroom as possible sources of this deficit in American children.

In a later study with undergraduates in a Graduate Records Examination preparation class, Richland and McDonough (2010) found that providing cues to support relational reasoning with an instructional analogy led to increased ability at post test, as compared to teaching the same analogy and solution strategies but without the cognitive support. These findings suggest that specific teaching strategies, like visually aligning the source and target problems, may be essential if students are to reap the full benefit of relational reasoning in the mathematics classroom. However, Stephens (2006) found that many pre-service teachers do not report providing instruction about relational reasoning as a priority, despite their awareness of its utility. This finding may suggest a need to further present the importance of relational reasoning, as well as some applicable cognitive supports for its use in mathematics learning, to educational practitioners.

Science

Publications that empirically linked relational reasoning to achievement in scientific domains highlighted the advantageous use of relational thinking in science instruction (e.g., Braasch and Goldman 2010; Zheng et al. 2008), text comprehension (Broughton and Sinatra 2010), and the expert performance of the professional scientist (Trickett et al. 2009). For example, in their study of 11th-grade chemistry students, Bellocchi and Ritchie (2011) observed that relational thinking allowed the classroom to transition into a scientific discourse from a discussion of everyday topics that were analogically related to the subject of study. Notably, Bellochi and Ritchie's (2011) study represents a sociocultural view on relational reasoning and illustrates the potential for analogical thought to move a collective classroom discourse toward the understanding of a scientific concept.

Multiple included studies have found that engaging students in relational reasoning about scientific topics by embedding an analogy in science instruction is a powerful tool for improving student performance (Braasch and Goldman 2010; Zheng et al. 2008; Trey and Khan 2008; Zheng et al. 2008). For example, Braasch and Goldman found that participants who read an expository text about weather systems, in which an analogy between weather patterns associated with El Niño and letting air out of a tire was included, had fewer misconceptions at post-test than a control group. Similarly, Trey and Khan (2008) found that dynamic computer based analogies—in this case an animated scale representing a chemical equation—enhanced high school students' knowledge of unobservable scientific phenomenon. Zheng et al. (2008) found a similar effect with elementary school students learning about electrical circuits using a computer interface that presented the material through the analog of water moving through pipes. Further, in their study of students with intellectual disability, Scruggs et al. (1994) found that participants were more likely to retain facts about animals if they were presented in a relational context, implying that supports for relational thinking may be useful for the study of science in the special education classroom.

Publications investigating the effect of refutation texts also report important findings for science education (Broughton and Sinatra 2010; Diakidoy et al. 2011). This line of research has provided evidence that students who read refutation texts had fewer misconceptions about the given topic at post-test than those that read expository text, even if they spent less time reading (Broughton and Sinatra 2010). This research paradigm demonstrates how supporting students' relational reasoning in science learning may lead to increased achievement.

It has also been shown that receiving training about pedagogy that incorporates relational reasoning—especially the analogy-based teaching of scientific concepts—can improve the teaching performance of pre-service teachers in the science classroom (James and Scharmann 2007). This finding suggests that, as in mathematics, relational reasoning can be fruitfully integrated into both teaching and learning in the science classroom. Further, Trickett et al. (2009) found that strategies for the resolution of anomalies strategies differ between experts and novices, suggesting that this form of relational reasoning continues to develop in professional scientists. Also, these strategies can differ in key ways based on the subject of study and the context of the problem at hand. These findings suggest that relational reasoning is not only important for the learning and teaching of scientific concepts but also for expert scientific practice in the professional setting. Collectively, this body of literature may imply that relational thinking is evident at multiple levels of scientific pursuit: learning, teaching, and expert performance.

Reading

Relational reasoning has been empirically linked to reading ability principally through early word reading (Ehri et al. 2009; Savage et al. 2011) and the reading of unusual or anomalous sentences (Ivanova et al. 2012). For example, the group of studies that focuses on the importance of relational reasoning in early reading acquisition (e.g., Savage et al. 2011) conceptualize words sharing the morphological relation of rime (e.g., *spoil* and *boil*) or rhyme (e.g., *light* and *bite*) as analogically related. Reasoning with morphological relations like these may be a useful way to expand students' phonemic awareness and ability to decode words (Ehri et al. 2009). Further, a deficit in this relational ability may partially explain reading difficulties associated with dyslexia (Schiff and Ravid 2007).

The study of participants' processing of verbal semantic anomalies also demonstrates ways in which relational reasoning ability can be linked to reading (Ivanova et al. 2012). For instance, passages containing inconsistent information about spatial relations or character traits reliably take participants longer to read—presumably because they must process and attempt to resolve the anomaly (Stewart et al. 2009). Further, those participants that fail to detect the anomaly in the first place generally do so because of shallow semantic processing (Bohan and Sanford 2008). Interestingly, it has been shown that bilingual participants reading in their second language are more likely to attend to an anomaly, and they experience a larger N400 effect upon noticing it than those reading in their first language, perhaps because they rely more heavily on a lexico-semantic network in their second language than in their first (Weber and Lavric 2008).

A recent theoretical paper by Alexander et al. (2012) also points to relational reasoning as an important ability associated with reading. This work points out that relational reasoning may help students to deeply process information from multiple sources and form an integrated knowledge base out of isolated pieces of information. This potential capacity of relational reasoning—perhaps of heightened importance in the particular technological environment of the twenty-first century—still needs to be empirically explored.

Writing

Writing has been implicated both as a domain in which relational reasoning ability plays an important role in achievement (Holliway 2007) and as an exercise useful in eliciting deeper level relational thinking in students (Klein et al. 2007). For example, in his study of elementary school students' writing, Holliway (2007) asked students to compose descriptions of abstract shapes. He found that these students used analogies, operationalized as metaphors or similes, to bridge the mental representations of writer and reader. This finding may suggest that instances of relational reasoning in students' writing may signify a more fully formed picture of the goals of their writing, as well as a deeper understanding of their chosen topic.

In their study with undergraduate students, Klein et al. (2007) found that writing may also facilitate relational reasoning about a given topic. Participants were asked to describe commonalities between two scientific demonstrations: Some did this through speaking only, while others composed a short descriptive passage. The students in the writing condition showed greater learning about the topic at post test, than those who did not write, and those participants who had a comparatively small working memory span benefited most from the writing exercise. Notably, the positive effect of writing was mediated by an increase in mapping of and reasoning with salient relations in that condition. This finding suggests that success in relational reasoning may rely on a careful consideration of the relations at hand. Consequently, the number of relations that a student can meaningfully consider at a time may affect the extent to which that student can employ relational reasoning in a given scenario. Moreover, the exercise of writing may encourage students to engage in relational reasoning in the first place.

Implications and Conclusions

Nearly 120 years ago, James (1890) described the power and importance of relational reasoning as being able to unite in a moment "what the whole breadth of space and time keeps separate." This quote was chosen as the epigraph to this review not only because it illustrates the capacity of relational reasoning to connect and bring together concepts and ideas divided temporally or spatially in our experience but because it also describes an intrinsic goal of this literature review as a whole. Part of the purpose of this review was to gather publications from a variety of fields incorporating diverse methodologies and presenting their evidence from often-divergent points of view and to bring them together as one body of work to be examined. This heterogeneous literature is united by its distinct inclusion of instances of relational reasoning in participants and can be unified by the evidence about the construct found within each piece of work. Despite the many differences in terminology and methodologies, the body of literature presented in this review has been brought together based on the inclusion of one of the theoretically identified manifestations of relational reasoning: analogy, anomaly, antinomy, and antithesis. For example, literature with such diverse foci as the cortical substrate of analogical reasoning (e.g., Krawczyk et al. 2010, 2011) and the comprehension of refutation texts in science learning (Broughton and Sinatra 2010) were included in this review because a manifestation of relational reasoning—as well as a possible applicability of findings to human learning and development—was evident in each.

We do not claim that the four manifestations of relational reasoning examined in this review constitute an exhaustive list. Nor do we claim to have identified every conceivable field of study in which relational reasoning can be made evident. Although the literature we analyzed in this review was a systematically gathered and comprehensive body of work based on our search parameters, in the future, additional forms of relational reasoning may be identified, or one of the already identified manifestations may be found to be applicable to yet another context. Because of this, we hold that there is still much work to be done in the study of this potentially pervasive mental ability.

We offer four underlying concepts identified in our analysis of the literature that we believe will be crucial to the study of relational reasoning going forward. These implications for the study of relational reasoning and its manifestations include: (a) the importance of incorporating a diversity of methodologies, participants, and measures; (b) the idea that relational reasoning necessarily involves relations between relations; (c) the potential for the identification of further instances of the construct at work; and (d) the characterization of relational reasoning as including a family of manifestations representing various relations that can arise when ideas or information is brought together.

A Diversity of Methodologies, Participants, and Measures

One identifiable thread that was present throughout the literature included in this review was an overreliance on particular methodologies, types of participants, and measures. Wherever this occurred, findings were less generalizable to the larger population, easily communicated to researchers working in different fields, and informative for theoretical discussion about the construct of relational reasoning.

Methodologies

For example, the heavy reliance of neuroscientific methods like fMRI and ERP in the literature pertaining to relational reasoning in general as well as anomaly possibly comes at the expense of ecological validity and the ability of the field to describe the construct at work in diverse contexts. In contrast, the research on analogy, which incorporated a wider variety of methodologies, afforded researchers the ability to make inferences about how analogical reasoning happens in many different circumstances.

It should be noted, however, that although the bodies of literature representing the neuroscience of relational reasoning and the construct's importance for the educational context are still largely separate, there is a clear opportunity to incorporate these findings. Knowledge of how learners' ability to reason with relations happens in the brain could inform inquiries into how the construct manifests itself in education, while a greater awareness of relational reasoning's role in the learning process could help frame attempts to explain this construct from a cognitive neuroscience perspective.

Further, the use of exploratory qualitative methods may be an important first step by those interested in examining understudied manifestations of relational reasoning like antinomy and antithesis. For example, the evidence exists to support the idea that experts in many domains engage with antinomies (e.g., Cole and Wertschb 1996; Matte-Blanco 1988; Mosenthal 1988). Also, theoretical arguments claim that antithesis may be a relation of fundamental importance for the organization of human cognition and language (De Saussure 2011; Kjeldergaard and Higa 1962; Marková 1987). Qualitative methods used to ascertain just how pervasive these forms of relational reasoning may be in human thought, and identifying key examples of them in action, may be an integral stage in any line of inquiry.

Participants

Another constraining factor identified in the literature we examined was the overreliance on undergraduate students as participants in experiments, especially in the literature on anomaly and antithesis. This dependence on undergraduates may be due in part to the research questions asked in this literature, which often focused on the modes of presentation and context of the relational stimuli being presented, and often did not require a variety of different types of participants to be addressed. Because most researchers in these fields seem to be currently interested in altering the nature of their measures and tasks, while keeping the participants relatively comparable, undergraduates are suitable for most experiments. However, this observation about the field could signal an opportunity to more frequently ask research questions—such as those regularly being asked by researchers working with relational reasoning in general or analogy—concerning lifespan development, or the ability of those with intellectual disability, that motivate the use of a variety of participants.

In the literature pertaining to analogy, the diversity of participants may allow the field to make important inferences about the development and use of analogical reasoning. For instance, Vakil et al. (2011) found that adults with intellectual disability generally performed worse than typically developing children on an analogy task even when the children and adults were matched for mental age. In contrast, Morsanyi and Holyoak (2010) found that analogical reasoning was largely intact in participants with autism. These findings provide an opportunity for insight not only into the differing abilities of these two populations and the effects of the disorders they represent but also into the cognitive and neural roots of analogical reasoning itself. They also indicate a chance to make similar comparisons not only within other fields of research but also between bodies of literature pertaining to different manifestations of relational reasoning.

Measures

Further, an overreliance on a particular measure or task to operationalize relational reasoning may also limit the scope of this research. For example, in the literature pertaining to anomaly, the predominance of research using verbal semantic anomalies meant that other potentially anomalous circumstances were underexamined. Importantly, the dependence on a particular measure or task can cause a mismatch between conceptualizations and definitions of relational reasoning and their operationalizations. For instance, while relational reasoning in general is frequently defined as a broadly applicable construct used for the integration of multiple relations, it has been operationalized all too often as roughly equivalent only to analogy. Our analysis of the literature reveals that this mismatch is driven in large part by the overreliance on a few measures and tasks—namely Raven's Progressive Matrices and four-term verbal analogies—by those working in this line of inquiry. This identification of the dominance of analogical reasoning in the literature on relational reasoning may be an opportunity for the field to contemplate ways to diversify the forms of relational reasoning being studied by identifying or creating measures designed to study other manifestations of the construct in participants.

Finally, the use of methodologies, measures, and participants that allow researchers to make conclusions about how relational reasoning and its manifestations may be linked to educational outcomes should be a priority for the field going forward. The observation that only about a quarter (25.7 %) of all the included studies empirically linked relational reasoning ability to success in a particular academic domain illustrates the need for more of this type of study to be conducted. It may be that uncovering relational reasoning's contribution to students' success in the educational context will promote future strides in this line of inquiry.

Relations Between Relations

Throughout the literature included in this review, the nature of the relations under study was of special interest. Each of the four forms of relational reasoning examined in this review (i.e., analogy, anomaly, antinomy, and antithesis) was characterized and differentiated from the other forms by the fundamental relation that arose between the sets of information being analyzed. For example, analogies are defined on the basis of a similarity relation, whereas anomalies are distinguished by their underlying discrepancy, antinomies by incompatibility, and antitheses by an inherent oppositional relation. These essential relations that define each form of relational reasoning and reflected in the research-based definitions summarized in Table 1 are indicative of the foundational mapping that occurs between clusters of information shaped through a series of initial associative processes.

These definitive relations (i.e., similarity, discrepancy, incompatibility, and opposition) that give each mode of reasoning its characteristic nature, however, are not the only manner of associations required to reason relationally. There are incalculable relations that are formed *within* some given set of information, as well as *across* sets of ideas, concepts, or objects. The variation between such relations is captured within theories of reasoning, such as Sternberg's (1977) componential theory, and their differing complexity or level of abstraction has been marked by such labels as *lower-order* and *higher-order* relations (Goswami 1992). The more local associations centered within an informational set would correspond to the components of encoding and inferring in Sternberg's (1977) componential theory and would generally fit within the category of lower-order relations (Goswami 1992).

Conversely, relations mapped across sets of information and between lower-order relations previously drawn would be classified as higher-order relations.

Each of the definitive relations that characterizes the forms of relational reasoning discussed in this review (i.e., similarity, discrepancy, incompatibility, and opposition) are relations mapped across sets, or between lower-order relations, and as such are higher-order or *relations between relations*. Crucially, without a between-set mapping of a higher-order relation, relational reasoning as we have defined it does not occur. In addition, because the higher-order relations that can be mapped between sets of information or between lower-order relations can differ, the characterization of the higher-order relation that is mapped determines which form of relational reasoning is being utilized in a given situation.

The distinction between higher- and lower-order relations can also be useful in interpreting findings in the relational reasoning literature. For instance, in their study of science instruction, Trey and Khan (2008) demonstrated that it was students' comprehension of the higher-order analogical relation of similarity between the balanced nature of a chemical equation and the balance of a scale that allowed them to understand the specific lower-order relations involved. Namely, students were able to reason that just as a scale does, each quantity present on one side of a balanced chemical equation must have its equal on the other side. This observation also implies that inquiries about the interplay between lower-order and higher-order relations could be potentially fruitful for uncovering how relational reasoning unfolds in the minds of students.

The Identification of Further Instances of Relational Reasoning

A conscious effort to broaden our current understanding of relational reasoning and its manifestations by identifying further instances of the construct at work can be deeply beneficial to both the study of relational reasoning itself and the field in which relational thought is identified. For example, the identification of morphological relations between words such as rime and rhyme as instances of analogy present in the work of Savage et al. (2011) has been shown to be fruitful not only for the study of analogical reasoning but also to the understanding of early reading acquisition. Similarly, the identification of incorrectly solved mathematical problems by Chen et al. (2007) as instances of anomaly allows for a program of research that examines relational thought, mathematical reasoning—and the interrelations between them—simultaneously.

The identification of further instances of understudied manifestations of relational reasoning like antinomy may be especially important going forward. While researchers in various fields may showcase their reasoning with antinomies in their scholarly writing, the identification of further instances of antinomy, especially in students and novice practitioners of a given discipline, may be particularly beneficial in the future.

Relational Reasoning as a Multidimensional Construct

One basic idea that has been foundational to the perspective of this review is that a broad conceptualization of relational reasoning as the ability to recognize or derive meaningful relations between and among pieces of information should include a family of relations that can arise when otherwise disparate information is encountered. In this review, we presented four possible manifestations of relational reasoning that may merit further study. As the field progresses, we perceive a need to keep the broad conceptualization of relational reasoning in mind and to continue to theoretically discuss, as well as empirically investigate the manifestations of relational reasoning, their interconnections, and their unique implications in the educational context.

For example, this review has identified a need to further explicate how each of these forms of relational reasoning can operate in concert to produce the phenomenon of complex relational thought. The beginnings of this effort are recognizable in the investigations of Dunbar (1995) and Trickett et al. (2009) into the reasoning of expert scientists. Because their naturalistic observation method allows them to observe the reasoning of scientists as it happens in vivo, the inter-related uses of the different forms of relational reasoning are potentially made evident. But there are still many questions left to answer. For instance, are certain forms of relational reasoning more pervasive in a given domain than other forms? Are certain strategies more or less adaptive for students given the form of relational reasoning at hand? How do students integrate the diverse relations they may encounter in a complex learning situation? How can relational techniques be used to improve the learning of all students? Each of these questions deserves careful consideration and extensive empirical study, and it may be years until an answer to any of them can be put forward. However, we believe that the identification of a new and potentially fruitful line of inquiry is itself a step forward for the field—a step that would never have been possible without the examination of the four forms of relational reasoning present in this review.

While most of the studies included in this review that presented outcomes related to educational success were correlational in nature and, thus, do not permit recommendations for educational practice (Reinhart et al. 2013), there are some aspects about the applicability of relational reasoning and its manifestations to the educational context that warrant consideration. For instance, it has been demonstrated that students' ability to reason relationally is predictive of success in a variety of academic domains and that the predictive relation differs depending on the form of relational reasoning and the academic domain being examined (e.g., Farrington-Flint et al. 2007; Schiff and Ravid 2007). Also, researchers who have endeavored to forge interventions around relational reasoning (e.g., Richland and McDonough 2010; Tzuriel and George 2009) have achieved some demonstrable success. These encouraging outcomes set the stage for future experimental and intervention research that can, subsequently, support recommendations for educational practice and academic development.

Relational reasoning may be as ubiquitous in human thought as Spearman (1927) suggested when he described it as the trees that form the forest of mental ability, or as Hofstadter (2001) argued when he portrayed it as the "very blue that fills the whole sky of cognition" (p. 499). After systematically gathering and analyzing the literature in which relational reasoning is evident, we can conclude that it is a possibly fundamental and widely applicable construct—with much potential to be examined in the context of learning and development—about which interest continues to grow.

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