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Individual differences in the process of relational reasoning☆

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ABSTRACT

The ability to discern meaningful patterns—relational reasoning—has been identified as a process important for student learning and cognition. Yet, research has typically investigated performance over processing, particularly when examining the role of factors such as working memory capacity. Moreover, studies have focused on analogical reasoning to the exclusion of other identified relational forms (i.e., anomaly, antinomy, antithesis). Study 1 investigates the role of individual differences in relational reasoning performance across four relational forms. Then, Study 2 identifies the highest and lowest-performing students from Study 1 to examine the probability that undergraduate students reach each of four sequential component processes of reasoning and the degree to which significant individual differences from Study 1 (i.e., visuospatial working memory) play a role in each process. Results indicate that low performing students experience particular difficulties in identifying relevant inferences and in mapping those inferences. This was due in part to the relation between working memory capacity and the processes of inferring and mapping. The outcomes from this study contribute to understandings of the sources of success and failure in reasoning for students at different levels, and identify potential entry points for intervention research.

1. Introduction

More than at any previous point in human history, today's students inhabit an educational landscape awash in information (Lenhart, 2015; Purcell et al., 2012). As such, learners must work continually to make sense of divergent data, identify trends within seemingly unrelated ideas, and recognize patterns within and across domains (Alexander et al., 2011; Bråten & Strømsø, 2010). Although the processes and abilities necessary to support student success in such endeavors are expansive, this investigation focuses on one intriguing and powerful cognitive capacity, relational reasoning (e.g., Gentner, Loewenstein, & Thompson, 2003; Gick & Holyoak, 1980; Richland & McDonough, 2010).

Relational reasoning, the ability to discern meaningful patterns within any stream of information (Alexander & the DRLRL, 2012; Bassok, Dunbar, & Holyoak, 2012), has long been regarded as a foundational cognitive ability (James, 1890/1950; Sternberg, 1977), and is widely considered critical for learning and academic performance (e.g., Farrington-Flint, Canobi, Wood, & Faulkner, 2007; Schiff & Ravid, 2007). Although reasoning about patterns of similarity (i.e., analogical reasoning) have dominated the educational literature (Dumas, Alexander, & Grossnickle, 2013), additional relational forms have been identified. Specifically, reasoning about patterns of aberrance (i.e., anomalous reasoning), incompatibility (i.e., antinomous reasoning), and opposition (i.e., antithetical reasoning) have emerged as forms of relational reasoning important for learning in many domains (Broughton, Sinatra, & Reynolds, 2010; Chinn & Malhotra, 2002; Kuhn & Udell, 2007; Sidney, Hattikudur, & Alibali, 2015).

Across various domains and levels of learning (e.g., Dumas, Alexander, Baker, Jablansky, & Dunbar, 2014; Ehri, Satlow, & Gaskins, 2009; Richland & McDonough, 2010), analogical reasoning has been found to correlate with a number of individual differences (Fleischhauer et al., 2010; Krawczyk, 2012; Mackintosh & Bennett, 2005; Morrison, Holyoak, & Truong, 2001), with working memory chief among them. Yet, studies examining individual differences factors in non-analogical reasoning have been limited. Moreover, relational reasoning has typically been examined as a capacity or ability measured through the outcomes of successful or unsuccessful performance on reasoning tasks. However, within the analogical reasoning literature, models acknowledge that successful

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relational reasoning requires the execution of a sequence of component processes (e.g., inferring or mapping) rather than any singular or gestalt process (Krawczyk, McClelland, Donovan, Tillman, & Maguire, 2010; Sternberg, 1977). What is unknown, is the degree to which students successfully engage in the component processes ascribed to analogical reasoning when reasoning about other relational forms (e.g., anomaly). Further, componential models propose that relational reasoning processes are sequentially dependent, that is, each preceding process must be completed in order to move on to the subsequent process (Lifshitz, Weiss, Tzuriel, & Tzemach, 2011; Sternberg, 1977). However, to our knowledge, no existing research examining the component processes of relational reasoning has utilized statistical methods examining the probabilistic dependence of these processes. The present study moves forward the statistical examination of the componential model of analogical reasoning by applying Bayesian network analysis to test the probability of successful completion of a given component process (e.g., mapping) predicated on the successful completion of the preceding component process (e.g., inferring).

These observed gaps in the literature have particularly important implications for educational practice and for the development of component-based training studies. For example, if a student appears unable to successfully reason relationally, the research literature currently offers limited empirically derived clues as to where their reasoning process may be breaking down or the degree to which other factors, such as working memory capacity, may be influencing specific components of the reasoning processes. Although previous studies have examined the effectiveness of component-based training for analogical reasoning (Alexander, White, Haensly, & Crimmins-Jeanes, 1987; White & Alexander, 1986), the extent to which these component processes apply to non-analogical forms of relational reasoning remains under-examined. Further, by investigating the degree to which individual differences such as working memory predict the component processes of analogical and non-analogical forms of relational reasoning, the present investigation provides insights into how these individual factors might support or hinder overall performance (Study 1) or the execution of specific components (Study 2). As such, inquiry into these gaps could prove diagnostically invaluable and become the basis for subsequent intervention.

Therefore, the present two studies focus on the identification and explication of specific junctures in the process of relational reasoning where individuals' performance may falter. To do this, Study 1 assessed students' performance on multiple forms of relational reasoning and related performance to relevant individual differences. Then, Study 2 identified high- and low-performing students from Study 1 and utilized conditional-probabilistic, or Bayesian, networks to uncover specific points in the reasoning process where certain students progress while others do not. Additionally, the significant individual differences from Study 1 were retained in Study 2 to examine how these characteristics related to critical points within the reasoning process.

2. Theoretical framework

2.1. Forms of relational reasoning

At its core, relational reasoning consists of identifying relations among relations, referred to as higher-order relations (Crone et al., 2009; Gentner, 1983; Krawczyk, 2012). Higher-order relations involve the identification of a pattern across seemingly disparate information (Gick & Holyoak, 1980; Goswami & Brown, 1990). This pattern is not simply the drawing of an inference between two ideas or objects (i.e., lower-order relations). Instead, it involves aggregating or mapping multiple lower-order relations in meaningful ways (Chi & VanLehn, 2012; Gentner, 1983; Holyoak & Thagard, 1989). Relational forms (i.e., analogy, anomaly, antinomy, antithesis) are characterized according to the type of higher-order patterns that are required (i.e., similarity, aberrance, incompatibility, opposition; Alexander & the DRLRL, 2012; Dumas et al., 2013). Although these higher order patterns are composed of lower-order patterns, it is the higher order patterns that distinguish the different forms of relational reasoning.

Clearly, the most commonly studied higher-order relation in the research literature is *analogy,* which requires a higher-order relation of similarity (Alexander, Dumas, Grossnickle, List, & Firetto, 2015). For example, a cell may be said to be relationally similar, or analogically related to, a factory because both are parts of a larger collective (i.e., a body or society) and contain interdependent parts with similar functions (e.g., the nucleus serves as the headquarters or manager). However, higher-order relations other than similarity have emerged within the theoretical and empirical literature: anomaly, antinomy, and antithesis (Dumas et al., 2013; Ferguson & Sanford, 2008; Stewart, Kidd, & Haigh, 2009; Tanca, Grossberg, & Pinna, 2010). Although these are not argued to be the only forms, they have been put forward as forms important for learning and development (Alexander et al., 2015; Dumas et al., 2013).

In contrast to analogy, which is predicated on a higher-order relation of similarity, *anomaly* involves the identification of cases that are aberrant and, thus, do not fit within an overarching scheme (Chinn & Brewer, 1993; Klahr & Dunbar, 1988; Kulkarni & Simon, 1988). Reasoning by anomaly requires the identification of a higher-order relation of discrepancy or deviation between the anomalous idea, object, or event and the others. To do this various lower-order patterns are identified among multiple objects or concepts within a body of information, and then a higher-order relation of discrepancy is mapped. For example, when statisticians work to identify outliers in a regression analyses, they must first consider the relations among all their data points in order to conceptualize a particular pattern (e.g., the regression line), in which most but not all of the cases fall.

A third form of relational reasoning, *antinomy*, requires the conceptualization of mutual exclusion between or among ideas (Chi & Roscoe, 2002; Cole & Wertsch, 1996; Sorensen, 2003). In this way, antimony requires the mapping of a higher-order relation of incompatibility among ideas, objects, or events whose lower-order relations have been characterized. For example, when a medical student learns to make accurate diagnoses, they practice “ruling-out” possible conditions by attending to the symptoms a patient is presenting and deciding whether those symptoms are compatible or incompatible with a given diagnosis (Dumas et al., 2014).

Finally, reasoning via *antithesis* involves the identification of a higher-order pattern of opposition between concepts (Bianchi, Savardi, & Kubovy, 2011; Kuhn & Udell, 2007). For example, in the educational context students may encounter refutation texts that present two directly opposing viewpoints on a given topic, such as climate change, which require students to conceptualize higher-order relations of opposition among the various lower-order relations in each argument (Sinatra & Broughton, 2011). Study 1 investigates the degree to which relevant individual differences (e.g., working memory capacity, need for cognition) are associated with performance on each of the forms of relational reasoning. Then, Study 2 examines the componential process of each of the forms of relational reasoning, with an eye towards identifying the point where that process collapses for low-performing students, and explaining that collapse with individual difference variables from Study 1. Additionally, Study 2 compares the degree to which students are more or less successful in executing the processes of relational reasoning across each of the four forms.