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Reading and mathematics equally important to science achievement: Results from nationally-representative data

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ABSTRACT

We investigated the importance of reading and mathematics achievement in the prediction of science achievement across time. By studying models of these achievement variables while controlling for important variables, such as socioeconomic status and general knowledge, a better understanding of how reading and mathematics support science achievement over time emerged. Data from Early Childhood Longitudinal Study-Kindergarten cohort was utilized as a nationally-representative and community-based sample of children across the United States. Findings provide a methodological improvement on previous literature by permitting the estimation of indirect effects, which provides the percent of the relationship accounted for at each time point. We found that reading achievement appears to significantly mediate the relationship between mathematics and science across time.

Science, technology, engineering, and mathematics are so commonly connected that even a single acronym, STEM, can be used to represent these fields as an aggregate. This high degree of relatedness suggests to educators that success in one area of STEM is associated with success in the others, and the research literature appears to support this conclusion. For example, mathematics achievement has been found to be highly correlated with science achievement and outcomes (e.g., Gustin & Corazza, 1994; Maerten-Rivera, Myers, Lee, & Penfield, 2010; O'Reilly & McNamara, 2007).

The core knowledge required in STEM fields, however, does vary considerably. Despite some differences within the field of science itself, science educators typically focus on knowledge of the natural world, understanding of the processes used to generate knowledge of the natural world, and appreciation of the collaborative nature of science (Lehrer & Schauble, 2006; National Research Council, 2007). Although mathematical skills are often required in the process of knowledge generation, reading skills are necessary to learn about what has been discovered. The shared, social nature of scientific study further warrants a considerable amount of reading and sophisticated level of comprehension. Everyday words can take on new and very specific meanings in a scientific context, which further emphasizes the need for advanced reading levels when studying science (Newcombe et al., 2009).

Interest in the association between reading and science achievement continues to emerge in the past decade (e.g., Bayat, Sekercioglu, & Bakir, 2014; Claessens & Engel, 2013; Kumtepe, Kaya, & Kumtepe, 2009; Maerten-Rivera et al., 2010; O'Reilly & McNamara, 2007). These studies are limited, as reading achievement has been either investigated at a specific developmental level or included as a covariate rather than a variable of interest. Some longitudinal analyses have been conducted (e.g., Claessens & Engel, 2013; Kumtepe et al., 2009) with a focus on predicting science achievement at a later grade from reading achievement at kindergarten; however, these studies failed to include the associations of measured achievement at each grade level. By extending the investigation to focus on autoregressive models that includes both mathematics and reading achievement variables assessed into the middle level years, a better understanding of the relative importance of reading achievement and mathematics achievement in the prediction of science achievement will emerge.

Although both mathematics and reading are implicated in children's successful science performance, initiatives to improve the science achievement of American youth are more likely to focus on mathematics alone. This strategy could be valuable as students approach secondary school science topics that rely more on mathematical applications to understand concepts. However, improving reading skills may, especially at the elementary level, be a more appropriate strategy to promote science achievement. The purpose of the present study was to investigate the relationship between reading, science, and mathematics achievement across four time points; kindergarten, third grade, fifth grade, and eighth grade. Specifically, the relative importance of reading and mathematics in the prediction of science achievement was

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evaluated through the evaluation of four models; a model with only mathematics achievement predicting science achievement at third, fifth, and eighth grade; a model with only reading achievement predicting science achievement at third, fifth, and eighth grade; a model including both reading and mathematics with mathematics serving as a mediator of reading achievement's prediction of science; and a model with both reading and mathematics with reading serving as the mediator of mathematics achievement's prediction of science.

1. The role of reading in science achievement

Although reading requires a variety of skills ranging from phonological awareness to making inferences, the ultimate goal is to extract the intended meaning of the author from print through the development of cognitive representations. Reading at a basic or foundational level is a prerequisite to comprehension and the subsequent development of cognitive representations as students must first be able to decode text (García & Cain, 2014; Kendeou, Broek, Helder, & Karlsson, 2014). In this way, reading opens doors to learning, as text once decoded by the reader offers knowledge and even instructions for skill building. Thus, the finding that reading skill is associated with academic achievement is not surprising (Claessens, Duncan, & Engel, 2009; Cooper, Moore, Powers, Cleveland, & Greenberg, 2014; Duncan et al., 2006; Stevenson & Newman, 1986; Stevenson, Parker, Wilkinson, Hegion, & Fish, 1976). When considered in the context of the Model of Domain Learning (MDL, Alexander, 1997), reading becomes particularly relevant to the development of science knowledge, as "there is a mutually beneficial relation between one's linguistic knowledge, as represented in the person's domain knowledge, and his or her knowledge of topics encrypted by that language" (Alexander, 2005, p. 418). MDL describes how learners' interest, knowledge, and strategy use progress and develop from acclimation to competence and to eventual proficiency in a domain (Alexander, 1997). MDL acknowledges the unique developmental paths of learners by domain as some learners may be more progressed in one domain over another (Alexander, 2004). Interest serves the learning process and the development of expertise by providing an underlying motivation for learners to pursue knowledge, which may initially be situational and progressing to an individual interest (Alexander, 2004).

As children develop reading strategies, such as developing inferences, their ability to fill in knowledge relevant to the content or topic of the text improves (O'Reilly & McNamara, 2002). Based on MDL as a theoretical perspective, students with better subject matter knowledge in both reading and science will benefit more from their homework reading, as they can fill in missing gaps and generate conclusions using reading strategies and existing knowledge. MDL also emphasizes the importance of strategic knowledge, which involves both general cognitive and metacognitive strategies (Murphy & Alexander, 2002). According to Murphy and Alexander, strategic knowledge is evident in general text-processing strategies, such as re-reading sections or, at a deeper level, relating what is read to existing knowledge. In view of MDL, reading ability would appear to be a pre-requisite to focusing the power of interest, enhancing knowledge, and executing strategies.

Unfortunately, not all school textbooks devote sections to background content or explicit explanations of how concepts are related (VanLehn, 1990, 1995). This makes students' existing subject matter knowledge especially important as it offers connections and even a structure to newly introduced information. "In terms of academic achievement, the role of domain knowledge is probably most critical for helping students to interpret and comprehend their textbook" (O'Reilly & McNamara, 2007, p. 163). Therefore, children who already possess science knowledge will gain more from their reading and those who possess less knowledge will fall further behind as they do not benefit from their reading. Unfortunately, researchers investigating the positive influence of early science and nature experiences intended to develop scientific knowledge on later achievement found little to no evidence to support this relationship (Kumtepe et al., 2009; Sackes, Trundle, Bell, & O'Connell, 2011). Thus, children's science knowledge development may depend on reading, especially in the context of public schools.

Despite an increasing emphasis on project based science learning (Driscoll, Moallem, Dick, & Kirby, 1994), standardized and high-stakes testing continue to demand an emphasis on traditional classroom methods, including textbook reading. For example, 64% of teachers in a 2002 study (NEA, 2002) reported using the textbook for student homework. Concern arises, however, with the finding that 74% of 8th grade students did not perform beyond basic reading levels on the National Assessment of Educational Progress (NAEP) in 1998 (National Center for Educational Statistics, 1999). Thus, as reading achievement develops, science knowledge develops and assists in better science reading comprehension and ultimately science achievement over time, which suggests that the development of reading skills should be emphasized in the efforts of improving science achievement.

Several researchers have documented the positive association between reading and science achievement. For example, O'Reilly and McNamara (2007) found that reading skill and reading strategy knowledge were positively associated with high school students' science achievement and reading skill helped students to compensate if their content knowledge was low. Therefore, the authors recommended that students read more about science in magazines and books to facilitate learning new information.

2. The role of mathematics in science achievement

Success in science also depends upon strategic knowledge in mathematics, which is supported by the moderate correlations found between mathematics and science achievement (Gustin & Corazza, 1994; Maerten-Rivera et al., 2010, Wang, 2005). Advocates of integrated science and mathematics courses explain that mathematical language and tools allow for the understanding of science (Batista & Matthews, 2002). For example, a student's recreation a Galilean gravity experiment requires the measurement of the speed of falling objects made of the same material that differ based on size. Measurement, data organization, and data analyses, which are all mathematical tools, facilitate the student's understanding of gravity. Thus, as students' mathematical skills and strategies develop and improve, students' ability to understand and achieve in science should also increase.

Ma and Ma (2005) provided empirical evidence to support this supposition. Using latent growth modeling as well as hierarchical analyses to control for individual and school characteristics, Ma and Ma found that growth in mathematics achievement between the seventh and twelfth grades was associated with growth in science achievement. They therefore concluded that science educators may need to look to mathematics assistance when helping struggling students such that, "improvement efforts of teachers in one subject without knowledge of students' learning problems in the other subject may not work at all" (Ma & Ma, 2005, p. 90).

Although the relation between mathematics and science achievement is apparent, a review of the literature revealed only a few investigations conducted at the elementary school level when mathematical skill is still emerging. Maerten-Rivera et al. (2010) evaluated the association between mathematics and science achievement in a sample of elementary school students, but the sample was drawn from fifth grade students. Interestingly, the authors found that reading achievement was a stronger predictor of science achievement than mathematics. "The results from our study suggest reinterpretation of the relationship of science to reading and mathematics, respectively, since reading achievement did have a larger effect size on science achievement than mathematics achievement" (p. 958). Thus, an investigation of the question of how both reading and mathematics relate to science