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A Longitudinal Investigation of Directional Relations Between Domain Knowledge and Reading in the Elementary Years

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ABSTRACT

The present study tested the postulation that "knowledge begets reading, which begets knowledge." Using Random Intercepts Cross-Lagged Panel Models (RI-CLPM), we analyzed a U.S. nationally representative data set to examine the directionality and magnitude of the longitudinal relation between domain knowledge (operationalized as science domain knowledge) and reading throughout the elementary years (from kindergarten to fifth grade), while accounting for important covariates, such as working memory, cognitive flexibility, English language proficiency, basic literacy skills, and demographic information. Moreover, we conducted multi-group RI-CLPM analyses to examine whether language status (being bilingual or monolingual) moderates the longitudinal relation between domain knowledge and reading. The results showed that the relation between domain knowledge and reading is bidirectional and positive throughout the elementary years, providing empirical evidence that domain knowledge and reading may mutually enhance with each other. In addition, language status did not moderate the relation between domain knowledge and reading, suggesting that the directionality and magnitude of the relation were similar between bilingual and monolingual students. Taken together, the results have important implications for integrating content knowledge and English language arts core instruction in elementary grades.

Reading is fundamental for problem-solving and effective communication (National Assessment of Governing Board, 2021) and a key competency for academic and career development (Snow, 2002). However, results of national assessments consistently show that many elementary students in the United States experience difficulties in reading. Indeed, more than 30% of fourth-grade students perform below a basic proficiency level, indicating difficulties in making inferences during reading (National Center for Education Statistics, 2015, 2017, 2019). These difficulties are likely to be exacerbated in later grades (Catts et al., 2005; Leach et al., 2003), particularly for bilingual students whose primary language at home is not English (Kieffer, 2010; Kieffer & Vukovic, 2012; Nakamoto et al., 2007). Therefore, longitudinal studies of reading development are needed to understand better how to prevent reading difficulties in bilingual and monolingual students as they advance through elementary school.

In an attempt to understand reading development, researchers have focused primarily on basic literacy skills (e.g., Gottardo & Mueller, 2009; Yaghoub Zadeh et al., 2012) and language proficiency (e.g., Lonigan et al., 2008; Mancilla-Martinez & Lesaux, 2010). Domain knowledge, defined as knowledge related to a field of study (Alexander & Judy, 1988; McCarthy & McNamara, 2021), is an understudied factor during reading

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development, despite its established importance (e.g., Kintsch, 1994; Perfetti & Stafura, 2014). According to the construction-integration model of text comprehension (Kintsch, 1998, 2013), domain knowledge can boost comprehension by facilitating generation of inferences during reading (McCarthy et al., 2018), and conversely reading can enhance domain knowledge because new information learned from reading can be incorporated into existing knowledge structures (Kendeou & O'Brien, 2014). That is, it appears that not only does domain knowledge contribute to reading development, but also reading influences the development of domain knowledge (i.e., there is a reciprocal relation; Cervetti & Hiebert, 2015; Connor, 2016; Duke et al., 2011).

Despite the importance of domain knowledge to reading, the current evidence base for the reciprocal relation between domain knowledge and reading—particularly how it might change over time—is weak because to date most studies have examined the relation concurrently (e.g., Hwang & Duke, 2020; Reed et al., 2017). Recently, a longitudinal study by Hwang (2020) demonstrated the positive role of early domain knowledge in reading growth throughout the elementary years, but did not investigate the bidirectional (or *reciprocal*) relation between domain knowledge and reading.

Thus, in this study, we investigated the directionality and magnitude of the longitudinal relation between domain knowledge (operationalized as science domain knowledge) and reading throughout the elementary years (Grade K-5) by analyzing a nationally representative large-scale longitudinal data set. We used a Random Intercept Cross-Lagged Panel Model (RI-CLPM) and accounted for individual differences in a variety of important covariates (early basic literacy skills, language proficiency, working memory, cognitive flexibility, and demographic information). Using this analytic approach allowed us to differentiate within-individual variance from between-individual variance, resulting in better estimation of the relation between domain knowledge and reading, nested in within-individual level (Hamaker et al., 2015). Revealing the directionality of the relation between domain knowledge and reading can have important implications for both theory and practice. With respect to theory, the findings can inform the refinement of existing models and frameworks to account for the hypothesized reciprocal relation. For example, most models strongly position prior knowledge as a contributor to reading, but few consider how reading influences knowledge acquisition and revision (Kendeou & O'Brien, 2014). With respect to practice, the findings can inform the design of interventions that emphasize and perhaps even integrate both domain knowledge and reading, rather than focusing on reading exclusively.

In addition, we examined the directionality and magnitude of the relation between domain knowledge and reading *separately* for bilingual and monolingual students. Examining these two groups is important given the high prevalence of bilingual and multilingual students in U.S. schools (Park & McHugh, 2014). Approximately one of five students grew up as bilingual in 2016 (The Annie E. Casey Foundation, 2018), and 10% of bilingual students in K-12 public schools are eligible for language assistance programs (National Center for Education Statistics, 2022). It is plausible that the process of reading development varies by language status (Aaron et al., 2008), and comparing the results between these two language groups can potentially inform how educators can support reading development of *all* students, including those who are bilingual (Lesaux & Kieffer, 2010).

Conceptual Framework

Reading is complex in that a variety of reader, text, and contextual factors, as well as interactions among these factors, influence reading development (Cartwright & Duke, 2019). Various models or frameworks of reading have been proposed to account for this complexity. Most of these models have commonly recognized the importance of prior knowledge (Cromley et al., 2010; Duke & Cartwright, 2019; Joshi & Aaron, 2000; Kintsch, 1998; Rapp et al., 2007). Prior knowledge can be defined as knowledge stored in long-term memory (Cook & Gueraud, 2005). Some theoretical models point to a reciprocal relation between prior knowledge and reading. According to the Construction and Integration (C-I) model of comprehension (Kintsch, 1998, 2013), readers' prior knowledge facilitates reading comprehension because it supports extracting ideas from text (i.e., microstructure) and identifying main ideas or themes (i.e., macrostructure), constructing the textbase representation. In turn, reading can support development of prior knowledge when the textbase is integrated with prior knowledge (i.e., building the situation model), which further enhances reading, and so on.

While the C-I model mainly focuses on the relation between prior knowledge and reading comprehension, the Lattice model (Connor, 2016) provides a broader picture of reading development by including a wide range of factors. The model explicates that development of prior knowledge influences reading comprehension, while development of and instruction to support reading comprehension simultaneously enhance prior knowledge. The model also postulates that the reciprocal relation between prior knowledge and reading is influenced by individual differences in code-based reading factors (e.g., letter knowledge, word reading), language-based factors (e.g., vocabulary, language comprehension), and cognitive and regulatory factors (e.g., working memory and cognitive flexibility). Drawing on the Lattice model, it is evident that accounting for individual differences in these factors is needed (Afflerbach, 2015) to accurately understand the reciprocal relation between domain knowledge reading development.

Operationalizations of Prior Knowledge

Reading researchers have operationalized prior knowledge in varying ways. In this paper, we adopt the contemporary view of prior knowledge based on the breadth and proximity of readers' knowledge to the text being read (Cervetti & Wright, 2020; McCarthy & McNamara, 2021). *Topic knowledge* refers to readers' knowledge about the topic of the text being read (Kendeou & O'Brien, 2016). Domain knowledge refers to broad knowledge related to a field of study (Alexander & Murphy, 1998) as opposed to a specific topic (e.g., Hwang, 2019; Hwang & Duke, 2020). Domain knowledge can be characterized as prior knowledge on multiple topics in *one* field, for example, science or social studies. The broadest operationalization of prior knowledge is general or academic knowledge, which refers to prior knowledge related to *multiple* domains or fields (McCarthy & McNamara, 2021). General knowledge can be assessed by asking information about multiple topics *across* different domains, for example, science *and* social studies (e.g., general knowledge measure used by Early Childhood Longitudinal Study—Kindergarten [ECLS-K] 1998–1999; Best et al., 2008; Hwang, 2020).

Pertinent to the present study is the operationalization of prior knowledge as domain knowledge in science. One caveat that needs to be acknowledged is that *not all* passages in the reading assessments used by ECLS-K include science topics. Instead, and accordingly to the test blueprint, the passages represent a variety of genres and topics. Thus, this operationalization lacks some precision regarding the proximity of readers' knowledge to the texts being read. It is likely that for some texts proximity will be close, for others somewhat close, and for others even far. Even though it would be tempting to operationalize knowledge as general knowledge to address this issue, such operationalization would not only lack precision, but it would also be inaccurate (given that what is evaluated in ECLS-K is science knowledge). Thus, we adopt the term domain knowledge with the caveat that the lack of precision inherent in the data set should be taken into account when conclusions are drawn.

The Potential Reciprocal Relation Between Domain Knowledge and Reading

Domain knowledge can facilitate reading because it can enhance text memory and inference-making, which can subsequently support learning from text. Strong domain knowledge consists of a well-organized, coherent structure of ideas related to a domain. The network of interconnected ideas can facilitate text memory because it expedites the process of activation and retrieval of ideas from long-term memory (Kintsch, 1988). Indeed, it has been observed that readers' domain knowledge is positively related to better recall of important ideas in text (Alexander et al., 1994; Miller, 2013). Miller (2013) demonstrated that domain knowledge can enhance recall of text even in readers with low working memory.

Domain knowledge can also support generation of inferences (Kendeou & Van Den Broek, 2005; McCarthy et al., 2018) needed to comprehend texts (McMaster et al., 2014). The coherent structure of domain knowledge can provide readers with resources to infer missing information in text (i.e., gap-filling inferences; McNamara & Kintsch, 1996). In addition, the hierarchical structure of domain knowledge (particularly science domain knowledge; Romance & Vitale, 2017) can inform the process of combining different parts of text (i.e., bridging inferences; Stahl et al., 1991) and guide readers to understand the relations among ideas in text (e.g., which ideas are superordinate or subordinate ideas).

Even when readers' domain knowledge does not have a direct connection to the text being comprehended (as may also be the case for some items included in the ECLS-K reading assessments), well-developed domain knowledge can support comprehension because interconnected idea units of domain knowledge can be adapted to serve as flexible schema to fit information from the text (Spiro et al., 1988, 1991). Indeed, when readers have developed strong domain knowledge, they are likely to have well-structured and elaborated schema, which can help them use their knowledge flexibly and establish connections between what they know and novel ideas, potentially resulting in better comprehension of novel materials (Kendeou & O'Brien, 2016; Kim et al., 2021; Spiro et al., 1988).

Reading can bolster development of domain knowledge (Alexander et al., 1994). In fact, reading is an essential means to learn about different domains (Goldman et al., 2016). Students are expected to develop domain knowledge in science and social studies by interacting with increasingly more texts as they move to upper grades (Duke & Carlisle, 2011). Skilled readers can comprehend texts better because they are more strategic in their generation of inferences (McNamara & Kintsch, 1996). They are more likely to use metacognitive reading strategies such as monitoring their thinking processes and summarizing text (Afflerbach et al., 2013; Pressley & Afflerbach, 1995). Moreover, skilled readers are likely to possess general vocabulary as they tend to be adept at learning words during reading (Perfetti et al., 2005). As vocabulary provides access to content in text, readers with strong vocabulary are in a better position to comprehend text and therefore develop domain knowledge from reading (Cohen, 2012; Taboada, 2012). Successful learning of domain knowledge from reading, in turn, can further bolster reading.

In summary, it is possible that domain knowledge can support reading and vice versa (i.e., there is a reciprocal relation between the two). It is equally important to note, however, that the relation between domain knowledge and reading can also be influenced by individual differences in basic literacy skills (e.g., word reading), language proficiency (e.g., language comprehension), working memory (the ability retain and manipulate information in mind; Miyake & Friedman, 2012), and cognitive flexibility (Connor, 2016). For example, having strong prior knowledge may not always bolster reading development when students have not yet developed sufficient word reading skills or language proficiency (Ross & Bradshaw, 1994; Wood et al., 1990). Inefficient word reading in early grades can overload working memory, creating a processing bottleneck and making it difficult to use domain knowledge to comprehend text (Perfetti et al., 1996). Low language proficiency in early grades can present challenges in integrating ideas from text with readers' domain knowledge, critical process for successful reading comprehension (Raudszus et al., 2018).

In addition, prior knowledge may not always support reading development when readers have limited working memory or cognitive flexibility, which are crucial components of executive functions (i.e., coordination of cognitive processes to maintain future goals; Welsh et al., 2006). Working memory supports the process of activating ideas from domain knowledge during reading, as well as integrating the ideas with those from the text being comprehended without buffer (Butterfuss & Kendeou, 2018; Follmer, 2018). When students start school with limited working memory capacity, it can be easily overloaded during reading and can decelerate the comprehension processes, making it difficult for readers to use what they know throughout the elementary years (e.g., Brandão & Oakhill, 2005). Cognitive flexibility enables handling multiple aspects of domain knowledge (e.g., distinguishing facts from opinions and relevance of ideas against the text being comprehended; Butterfuss & Kendeou, 2020), and thus facilitates connection and reconnection of different aspects of knowledge with different parts of the text being comprehended (Stylianou, 2020). Limited cognitive flexibility in early grades can present challenges to students throughout the elementary years in recognizing different aspects of domain knowledge and evaluating their relevance to text being comprehend, which can interrupt the process of leveraging domain knowledge to comprehend text (Denton et al., 2020).

Another possibility is that reading might not always support domain knowledge. To strengthen domain knowledge, readers need to integrate what the text says with what they already know and store the integrated knowledge representation in long-term memory (Kintsch, 2013). That is, even though good reading skills are needed to comprehend text, they might not be sufficient to facilitate domain knowledge development because building new domain knowledge would essentially depend on prior domain knowledge. In addition, limited working memory in early grades can interrupt learning from text and strengthen domain knowledge throughout the elementary years because overloaded working memory can decelerate the process of storing new knowledge gained from reading in long-term memory (Miller-Cotto & Byrnes, 2020). Limited cognitive flexibility in early grades can impede constructing a coherent mental representation of text and acquiring new knowledge throughout the elementary years because it can hinder flexible use of reading strategies (e.g., rereading, adjusting reading speed; Follmer, 2018). With limited cognitive flexibility, readers can encounter difficulties in detecting and remedying comprehension breakdowns (Denton et al., 2020; Kieffer et al., 2013).

Drawing on the extant literature, it is plausible but still unclear whether domain knowledge and reading have a bidirectional relation; thus, the directionality of the relation between the two requires further investigation. A longitudinal study is needed to simultaneously explore whether earlier domain knowledge can predict later reading and whether early reading can predict later domain knowledge. In so doing, individual differences in basic literacy skills, English language proficiency, working memory, and cognitive flexibility should be accounted for to better estimate the longitudinal relation between domain knowledge and reading. Adding demographic covariates that have been observed to explain variance of reading and knowledge development (e.g., age, gender, race/ethnicity, socioeconomic status [SES]) in previous research (e.g., Clotfelter et al., 2009; Kieffer, 2008; Quinn, 2018; Stanovich et al., 1984) can refine the estimation as well.

Empirical Evidence for the Relation Between Domain Knowledge and Reading in the Elementary Years

Consistent with the extant literature on older students and adults, studies with elementary school students have shown that domain knowledge predicts reading. For example, Hwang and Duke (2020) demonstrated that science domain knowledge predicted reading comprehension in third-grade bilingual and monolingual students. Hwang (2019) reported that science domain knowledge explained variance in reading comprehension in different languages in fourth-grade bilingual and monolingual students living in five countries. Whereas Hwang (2019) found that the magnitude of the relation between domain knowledge and reading was similar between the two language groups, Hwang and Duke (2020) observed the magnitude of the relation was stronger in bilinguals than monolinguals, indicating the role of language status as a moderator of the relation between domain knowledge and reading. Other studies have shown that reading predicts domain knowledge. For example, Reed et al. (2017)

showed that reading was consistently associated with science domain knowledge in fifth-grade students, regardless of levels of students' science domain knowledge. Duke et al. (2021) demonstrated that supporting second-grade students' reading led to enhancing social studies domain knowledge, providing evidence for the positive role of reading in social studies domain knowledge.

Despite evidence supporting the relation of domain knowledge to reading, and reading to domain knowledge in the elementary years, few studies have been conducted to evaluate the hypothesized relations longitudinally. For example, the most related study appears to be Hwang (2020) that examined the role of early general (academic) knowledge of science and social studies domains on reading growth. The study showed that early general (academic) knowledge of the two domains at the beginning of schooling predicted reading growth throughout the elementary years in bilingual and monolingual students. The magnitude of the longitudinal relation between early general (academic) knowledge of science and social studies and reading growth was similar between the two language groups. Morgan et al. (2016) reported that reading achievement at first grade predicted growth in science domain knowledge from third through eighth grades. However, these previous longitudinal studies are limited such that they have not investigated the directionality of the relation between domain knowledge and reading. To make matters more complicated, it is also plausible that the longitudinal relation between the two would rely on language status of students by home language (i.e., bilingual or monolingual).

The longitudinal relation between domain knowledge and reading can differ by language status, which can be explained in two ways based on previous research—a complementary mechanism of more exposure to English (i.e., being monolingual) and a compensatory mechanism of domain knowledge. The relation between domain knowledge and reading might be stronger in monolingual students than bilingual students because monolingual students typically have more exposure to English and have better English language proficiency that can facilitate using domain knowledge to comprehend text (i.e., the complementary mechanism of being monolingual; Carrell, 1983). On the other hand, bilingual students are developing two languages simultaneously and often have less exposure to English (Galloway & Lesaux, 2017); thus, they may have limited English proficiency, which can make it difficult to effectively leverage their domain knowledge to comprehend text or gain knowledge from reading (Hammadou, 1991). Alternatively, some scholars have argued that domain knowledge can support reading in bilingual students more so than in monolingual students because it can play a compensating role for bilingual students' relatively limited English proficiency (Hwang & Duke, 2020). This finding is analogous to the classic compensatory role of domain knowledge for lower reading skill (Recht & Leslie, 1988).

The Present Study

As the previous brief review of the literature has highlighted, two important gaps remain regarding the relation between domain knowledge and reading: (a) the directionality of the relation, and (b) the potential of language status to moderate the relation. To address these gaps, we investigated the magnitude and directionality of the relation between domain knowledge and reading longitudinally throughout the elementary years while also examining the moderating role of language status. To do so, we analyzed a nationally representative large-scale data set, which can potentially enhance generalizability of the findings, using RI-CLPM (Mulder & Hamaker, 2021) as an analytic approach and accounting for a variety of covariates to overcome a serious limitation of traditional CLPM that cannot separate the between-person variance from the within-person variance (Hamaker et al., 2015).

Two specific research questions guided the study: First, do domain knowledge and reading have unidirectional or bidirectional relations longitudinally from kindergarten to fifth grade? Drawing on studies that demonstrated the positive role of domain knowledge in reading (e.g., Hwang, 2019), as well as studies that showed the positive role of reading in domain knowledge (e.g., Reed et al., 2017), we hypothesized that domain knowledge and reading will have positive, bidirectional relations. Second, does language status influence the relation between domain knowledge and reading from kindergarten to fifth grade as a moderator? Given the importance of language status in academic achievement (e.g., Hwang & Duke, 2020), we hypothesized that the relation would vary for monolingual and multilingual students; however, we did not have specific expectations as to the nature of these variations (i.e., complementary mechanism vs. compensatory mechanism).

Method

Data Set

Samples in this study were drawn from publicly available data from the Early Childhood Longitudinal Study—Kindergarten Cohort of 2010–2011 (ECLS-K: 2011; Tourangeau et al., 2015), a national study conducted by the National Center for Education Statistics (NCES). The study used a publicly available, non-identifiable data set; thus, it was deemed exempt from review by and approval of the institutional review board of the University of Minnesota. The ECLS program was designed to provide information about children's educational experiences from kindergarten through elementary years, collected from multiple informants such as children, parents, and school administrators. The NCES used a multistage probability sample design to recruit a nationally representative sample of children from diverse backgrounds in the United States. The ECLS-K:2011 study began with a cohort of students in their kindergarten year (2010–2011) and followed this cohort through their fifth-grade year (2015–2016). Initial data were collected on 18,174 students in the fall of kindergarten; however, data were not collected from all students at later waves of data collection, due to sample attrition. The analytic sample includes 10,706 students whose reading and science scores were available from kindergarten through fifth grade. Demographic characteristics of the analytic sample in the present study are in Table 1.

Measures

The measures of main interest of the study include reading and science domain knowledge (spring of K-5). Trained assessors individually administered the measures in English. Students were asked to respond to the test items simply by pointing to their answers or telling their answers to the assessor without having to explain their reasoning (Tourangeau et al., 2015, 2019), which might have reduced linguistic demands of the measures. In addition, the measures were only administered to students who passed an English language screener test (Duncan & De Avila, 1998) as the ECLS-K considered them proficient in English sufficiently to proceed with the cognitive measures in English. Approximately 96.7% of the students passed the screener

TABLE 1
Means, Standard Deviations, and Frequency of Variables

Reading and Science IRT scores (spring)	Mean	SD	*N*	Moderator—Language status		Frequency (%)	*N*
K Reading	70.62	14.68	10,706	Bilingual		21	2041
Grade 1 Reading	96.66	17.48	10,706	Monolingual		79	7677
Grade 2 Reading	113.89	16.44	10,706	Covariate—Gender			10,693
Grade 3 Reading	122.30	14.93	10,706	Female		49	5240
Grade 4 Reading	130.53	14.35	10,706	Male		51	5453
Grade 5 Reading	137.60	15	10,706	Covariate – Race (*N* = 10,698)			9718
K Science	34.52	7.37	10,706	Native Hawaiian/Pacific Islander		0.55	59
Grade 1 Science	43.92	10.28	10,706	American Indian/Alaska Native		0.86	92
Grade 2 Science	53.62	11.47	10,706	Two or more races		4.10	439
Grade 3 Science	61.22	11.59	10,706	Asian		8.56	916
Grade 4 Science	67.82	11.56	10,706	Black/African American		9.69	1037
Grade 5 Science	74.50	12.31	10,706	Hispanic[a]		27.39	2931
				White		48.83	5224
Covariates				**Covariates—ages[b]**	**Mean**	**SD**	***N***
K EBRS	13.86	4.18	9475	K Age	73.63	4.48	10,698
K ELP	18.72	2.72	9491	Grade 1 Age	85.55	4.49	10,705
K Working memory	98.13	14.52	9402	Grade 2 Age	97.64	4.46	10,705
K Cognitive flexibility	14.48	3.09	9406	Grade 3 Age	109.15	4.48	10,705
K SES	−0.05	0.78	9703	Grade 4 Age	121.15	4.5	10,705
				Grade 5 Age	133.16	4.48	10,705

Note. EBRS = Early Basic Reading Skills (fall semester); ELP = English Language Proficiency; K = Kindergarten; SES = socioeconomic status.
[a]Hispanic has two categories: Hispanic, race specified (*N* = 2798) and Hispanic, no race specified (*N* = 133).
[b]Ages are in months (spring semester for each grade).

in their kindergarten year (see the section for "Kindergarten English Language Proficiency"). The ECLS-K concluded that nearly all students in first grade (99.9%) were proficient enough in English to understand the test directions in English; thus, the screener was not administered from second grade onward. Moreover, analysis of Differential Item Functioning was conducted to examine the presence of any potential bias related to students' different demographic backgrounds (e.g., race/ethnicity, gender). Upon the analysis and review of test items, ECLS-K reported that biases were not observed in any of the measures (Najarian et al., 2018, 2019).

Reading and Knowledge Measures for the Longitudinal Reciprocal Relation

K-5 Reading

The reading measures were based on the 2009 National Assessment of Educational Progress Reading framework (National Assessment Governing Board, 2008) and state curriculum and standards for reading (Najarian et al., 2018, 2019). The measures assessed students' basic skills (e.g., phonological awareness, recognition of letters), vocabulary (receptive and expressive vocabulary knowledge), and text comprehension (locate/recall, integrate/interpret, critique/evaluate) in English. The percent of test items for basic skills was the largest in kindergarten and decreased through second grade. From third grade, there were no test items for basic skills, and test items focused on capturing students' vocabulary knowledge and text comprehension. In this study, we used Item Response Theory (IRT) scores for reading from spring of kindergarten through fifth grade to fit RI-CLPM to ensure time intervals were constant in the longitudinal model. The reliabilities of IRT-based scores (computed as the ratio of within-child measurement error to total variance [across the sample]) for reading measures for each spring of first through fifth grade ranged between .86 and .95 (Najarian et al., 2018, 2019).

K-5 Science Domain Knowledge

Domain knowledge in the study was operationalized as science domain knowledge using IRT scores for science measures. We used science scores for spring of kindergarten through fifth grade to fit the longitudinal model with reading scores collected from the same time points. The science measures were aligned with the 2009 NAEP Science framework (National Assessment of Governing Board, 2008) and state science standards (Najarian et al., 2018, 2019). Test items can be classified into four content categories including scientific inquiry (e.g., using measurement tools), physical science (e.g., states of matter), life science (e.g., plants and animals), and earth and space science (e.g., Sun and Earth). Each category took the same portion (25%) of science tests for each grade. The reliabilities of IRT-based scores for science measures for each spring of first through fifth grade ranged between .82 and .86 (Tourangeau et al., 2019).

Language Status as a Moderator

To identify bilingual and monolingual students, we used a composite variable for students' primary home language in kindergarten, created by the ECLS-K from the parent survey. The composite variable classified students based on their primary or sole language: (a) A language other than English was primarily or solely spoken at home, (b) English and another language were spoken at home equally or it was not possible for the respondent to select a primary language, or (c) English was primarily or solely spoken at home.

In the present study, we considered the first and second groups of students bilingual because they were developing proficiency in two languages simultaneously. In the U.S. context, they were likely to speak in English outside of their home, while they were speaking a language other English at least half of the time at home. We regarded the third group as monolingual students. These students spoke English only or primarily at home, and they were likely to speak English outside of home in the U.S. context. It is possible that those who occasionally spoke a language other than English at home might have developed proficiency in two languages, albeit in an unbalanced way. However, considering most communication is conveyed in English outside of the home in the U.S. context, it appears that they spoke English disproportionately more than another language. In addition, it is impossible to distinguish students who spoke English only at home from students who spoke English primarily at home in the ECLS-K data set.

Individual Differences as Covariates

Kindergarten Early Basic Reading Skills

Kindergarten *Early Basic Reading Skills* (EBRS; as termed by the ECLS-K) consisted of a subset of items in the full kindergarten reading measure. The EBRS items assessed students' letter recognition and understanding of letter–sound relations, phonemic awareness, vocabulary, and sight word reading (Najarian et al., 2018). Unlike the other measures, the EBRS was administered to all students in kindergarten, regardless of students' performance on the language screener. The reliability of IRT-based scores for kindergarten EBRS was .99. The ECLS-K provided a raw score for the EBRS in the data set.

Kindergarten English Language Proficiency

The ECLS-K used two tasks from the Preschool Language Assessment Scale (*pre*-LAS; De Avila & Duncan, 2000) to determine whether a child's English language proficiency was sufficient to receive other cognitive assessments in English. In one task (*Simon Says*), the assessor gave simple, direct instructions in English to a child (e.g., point to the floor) to see whether the child could follow the instructions. The other task (*Art Show*) was to assess children's expressive vocabulary. The assessor showed pictures and requested a child to say the word in English that a picture represented. While the measure for English language proficiency was included as a covariate to account for between-individual differences in the model for the two research questions, it did not override language status, which was included as a moderator in the model for second research question. The passing rate of the test for English language proficiency was 96.7%, indicating that it was an easy test for both language groups. The ECLS-K provided the total score that represents the raw count of correct responses. Alpha coefficient for internal consistency of the measure was .91 (Tourangeau et al., 2015).

Kindergarten Working Memory

Working memory in the participants' kindergarten year was measured with the Numbers Reversed subtest of the Woodcock Johnson III (WJ III; Woodcock et al., 2001). This subtest consists of backward digit span tasks that require the child to repeat the numbers presented orally by the assessor in the reverse order. For example, if the assessor would say "one, five, three," then the child is expected to respond "three, five, one." Students started from five 2-number sequences. Increasingly, longer sequences were presented to students based on their performance, and the maximum sequence consisted of eight numbers. We used the *grade standard score* in the data set for working memory because it is better suited when one time point measure (fall of kindergarten) is included in analyses. The score indicates children's scores relative to other children in the same grade normed for WJ III. The split-half reliability of the subtest from the standardization sample was .87 (McGrew & Woodcock, 2001).

Kindergarten Cognitive Flexibility

Cognitive flexibility in fall of kindergarten was measured with the Dimensional Change Card Sort (DCCS; Zelazo, 2006). In this test, the assessor requested the student to sort 22 picture cards into two categories following particular sorting rules. Each card shows either a blue boat or a red rabbit. The test consisted of three tasks, presented as games to students. The first task was the Color Game; students were asked to sort the cards by color. For example, red boat cards were expected to be sorted into the red rabbit tray. In the second task, the Shape Game, the rule was to classify the cards by shape. A red boat card, for instance, was expected to be placed in the blue boat tray. The third task was the Border Game, in which students were asked to sort by color when the card displayed a black border. When the card did not display a black border, the rule was to sort cards by shape. Because the third game was more complicated than the first two, it was administered only to students who correctly sorted four of six cards in the Shape Game. The ECLS-K provided the total score that represents the accuracy of sorting the cards. The reported test–retest reliability coefficient was .92 (Zelazo et al., 2013).

Demographic Information

We included race/ethnicity, gender, SES, and students' ages at each time point as demographic covariates in the analyses. These covariates have been observed to explain variance in students' academic achievement (e.g., Cantin et al., 2016; Harwell et al., 2017; Logan & Johnston, 2009; Myrberg & Rosén, 2008); thus, including them can better estimate the relation between domain knowledge and reading.

The ECLS-K provided composite variables for race/ethnicity and gender. The composite variable for race/ethnicity was derived primarily from the parent interview. When a response from the parent interview was missing, the record by the assessor was used to inform the child's race/ethnicity. The race/ethnicity composite variable included eight values: White (non-Hispanic), Black or African American (non-Hispanic), Hispanic (race specified), Hispanic (no race specified), Asian (non-Hispanic), Native Hawaiian or other Pacific Islander (non-Hispanic), American Indian or Alaska Native (non-Hispanic), and More Than One Race (non-Hispanic). The white group was used as the reference group in the present study. The composite variable for gender was derived from the record by the assessor and parent interview. The composite variable for gender included two values, female and male. The male group served as the reference group.

The ECLS-K created a composite variable for SES using parent interview data from the kindergarten year (Tourangeau et al., 2015). They determined SES of households with the following components: parent 1/guardian's education and occupational prestige score (based on the 1989 General Social Survey prestige score), parent 2/guardian's education and occupational prestige score, as well as household income. After combining the five components, the ECLS-K standardized the composite variable (ranging between −2.4 and 2.6). In addition, the ECLS-K data collection window for each wave lasted roughly 3 months. Students who tested later in each period of data collection were likely to receive more instructional support and might have developed higher cognitive maturity than younger students, although they were in the same grade level. Thus, we controlled for students' ages at different assessment time points (each spring semester from kindergarten through fifth grade).

Data Analytic Strategy

An RI-CLPM was used to answer the first research question (directionality and magnitude of longitudinal relation between [science] domain knowledge and reading in the elementary years). RI-CLPM is one of the most cutting-edge extensions of traditional CLPM and can yield a less biased estimate of how constructs are related to each other than the traditional approach. While traditional CLPM cannot distinguish within- and between-person variance, RI-CLPM can account for stable between-person differences by including random intercepts and therefore display cross-lagged relations at the within-person level more accurately (Hamaker et al., 2015). Because it is plausible that between-person variance is not stable during K-5, we tested this possibility by constraining the variances of the random intercepts and their covariances to zero and comparing chi-square statistics when there were no constraints in the model (Hamaker, 2018). The chi-square difference indicated that the model fit the data better when there were no constraints (χ^2 [3] = 429.14, $p<.001$), suggesting stable between-person differences in the growth trajectory of reading and science knowledge. Thus, we selected the models without these constraints. We also included a variety of covariates to better account for between-person variance in the model.

For the second research question, we used multi-group RI-CLPM to conduct moderator analyses because it enables investigating whether path coefficients can differ across groups (Mulder & Hamaker, 2021). Also, using multi-group RI-CLPM did not compromise model fit. Students were categorized into two groups based on language status (i.e., bilingual or monolingual). When the moderator, language status, was examined, the same covariates in the RI-CLPM for the first research question were included in the multi-group RI-CLPM. Data for each pair of groups were examined simultaneously using multi-group RI-CLPM. Constraints were imposed to make path regression coefficients identical between the two groups and were relaxed later. A chi-square difference was computed to test whether multi-group RI-CLPM with the equality constraints or one without them explained the data better. When the result of chi-square test was significant, it revealed that RI-CLPM without the equality constraints fit the data better, indicating that the paths are moderated by the group membership and there would be differences in path coefficients between the groups. Conversely, when the chi-square test indicated that imposing the constraints fit the data better, this indicates no moderation effect (Mulder & Hamaker, 2021).

In addition, we included a sampling weight for analyses based on the ECLS-K manual (Tourangeau et al., 2019). School IDs were used as a cluster variable to adjust for any non-independence of observations. Analyses were conducted with *Mplus* version 7 (Muthén & Muthén, 2015), and missing data were handled with the full information maximum likelihood estimator. To evaluate model adequacy, we used three fit indices: Comparative fit index (CFI) and Tucker–Lewis Index (TLI) greater than .90, as well as a root mean square error of approximation (RMSEA) less than .08 (Hu & Bentler, 1999; Kline, 2011).

Results

Preliminary Analyses

Table 1 summarizes descriptive statistics for science and reading IRT scores, covariates, and a moderator (language status). Both science and reading scores tended to increase as students progressed to upper grades. Correlation coefficients among science and reading scores (spring of K-5), EBRS (fall of K), English language proficiency (fall of K), working memory (fall of K), and cognitive flexibility (fall of K), and SES are provided in Table 2. All coefficients were statistically significant.

Directionality and Magnitude of the Longitudinal Relation Between Science and Reading (RQ 1)

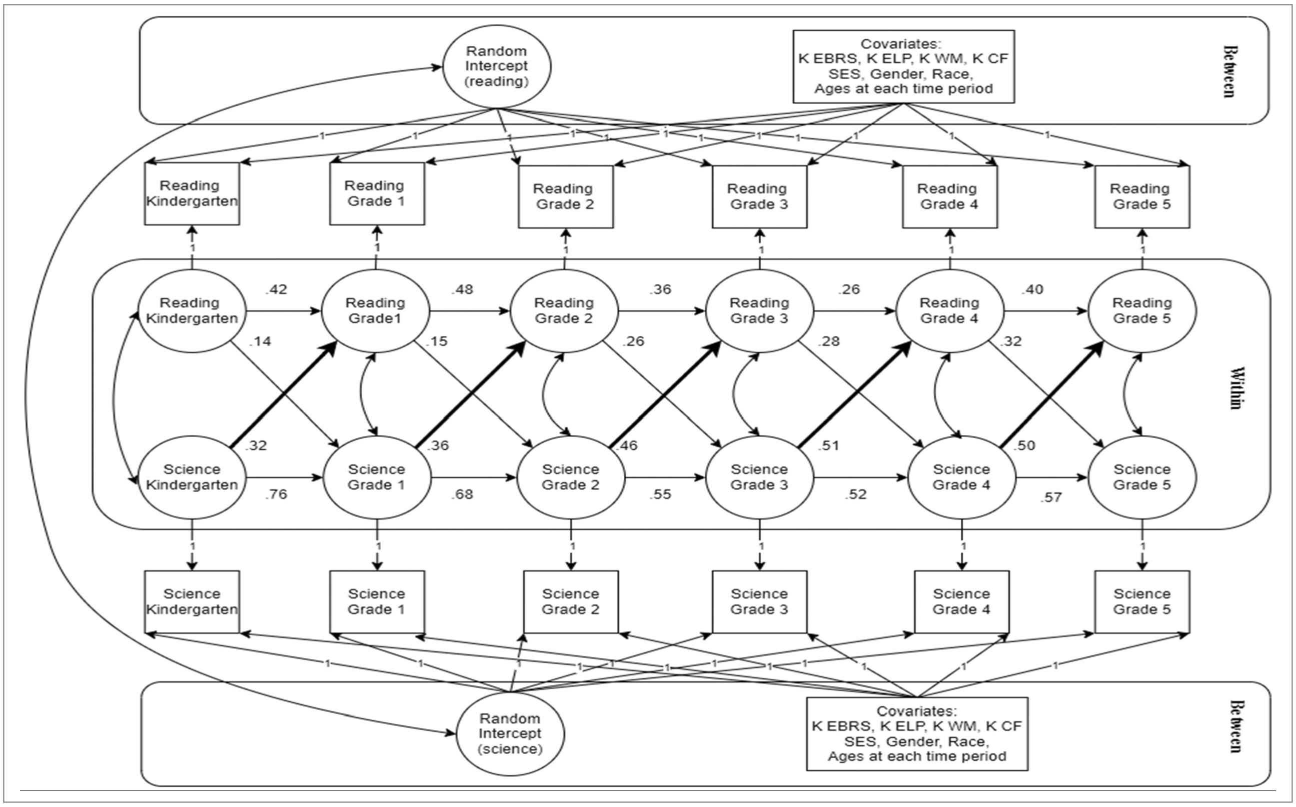
To answer the first research question (*Do domain knowledge and reading have a uni- or bi-directional relation throughout the elementary years?*), we examined RI-CLPM by fitting data for science and reading scores, as well as covariates to the model (see Hamaker, 2018; Mulder & Hamaker, 2021 for descriptions of how to specify RI-CLPM in Mplus). The model fit the data well (CFI = .964, TLI = .942, RMSEA = .034). All autoregressive paths from earlier reading to later reading scores, as well as from earlier science to later science scores, were statistically significant throughout the elementary years (K-5; see Figure 1). In addition, all cross-lagged paths from earlier science to later reading scores and from earlier reading to later science scores were statistically significant throughout the elementary years. EBRS, English language proficiency, working memory, and cognitive flexibility (all kindergarten measures) were significant covariates except the coefficients of English language proficiency on reading in first, second, and fourth grades (see Supplementary File for coefficients of the covariates).Coefficients for the cross-lagged paths from earlier science to later reading scores consistently produced larger numbers than those from earlier reading to later science scores. Thus, we tested whether the cross-lagged paths of the different directions (i.e., science to reading vs. reading to science) were statistically different in magnitude. We first constrained the two cross-lagged paths (the different directions) for each time point to be equal (e.g., making the coefficient of the cross-lagged path from kindergarten reading to first-grade science and that of the cross-lagged path from kindergarten science to first-grade reading equal). Then we relaxed them, and then compared chi-square values between when constraints on the paths were imposed and when constraints were freed.

TABLE 2
Correlations Among Reading and Science Scores, EBRS, English Language Proficiency, Working Memory, Cognitive Flexibility, and SES

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	K Reading																
2	G1 Reading	0.76															
3	G2 Reading	.67	.85														
4	G3 Reading	.61	.76	.84													
5	G4 Reading	.61	.76	.83	.83												
6	G5 Reading	.57	.73	.80	.82	.85											
7	K Science	.48	.51	.55	.59	.57	.57										
8	G1 Science	.54	.60	.62	.66	.63	.63	.77									
9	G2 Science	.56	.63	.68	.71	.68	.69	.72	.81								
10	G3 Science	.54	.63	.69	.75	.72	.72	.69	.78	.83							
11	G4 Science	.49	.59	.65	.70	.71	.72	.66	.74	.79	.83						
12	G5 Science	.49	.58	.64	.69	.70	.75	.64	.71	.76	.80	.84					
13	K EBRS	.63	.64	.58	.54	.52	.51	.48	.50	.50	.48	.46	.45				
14	K ELP	.28	.32	.33	.33	.31	.31	.49	.46	.40	.37	.35	.32	.42			
15	K WM	.49	.52	.51	.51	.49	.47	.45	.48	.49	.48	.45	.44	.48	.31		
16	K CF	.24	.28	.28	.30	.29	.28	.32	.35	.35	.34	.34	.34	.26	.25	.3	
17	SES	.34	.38	.41	.41	.42	.40	.42	.42	.41	.42	.40	.38	.33	.29	.33	.18

Note. CF = cognitive flexibility; EBRS = Early Basic Reading Skills; ELP = English Language Proficiency; G1 = Grade 1; G2 = Grade 2; G3 = Grade 3; G4 = Grade 4; G5 = Grade 5; K = Kindergarten; SES = socioeconomic status; WM = working memory. All coefficients were statistically significant at .001 level.

FIGURE 1
Random Intercept Cross-Lagged Panel Model (RI-CLPM) for All Students



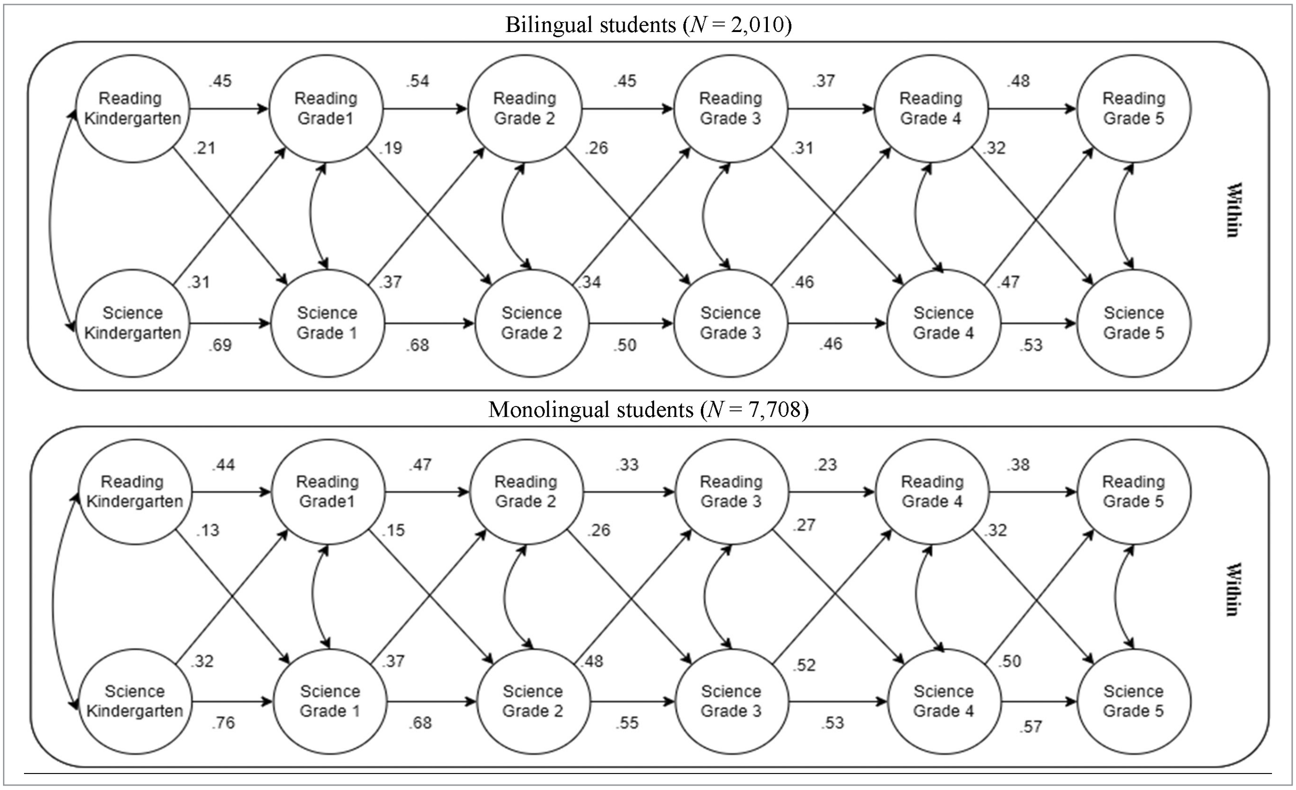
Note. N = 10,686; K = kindergarten; all cross-lagged and autoregressive paths were statistically significant at .001 level. A path with a thicker line represents a greater coefficient than the coefficient of the corresponding path. Covariances are shown in Table S1. Coefficients of covariates are shown in Table S3.

We first compared all path coefficients jointly rather than individually because a joint test has more power for the statistical test to reveal which models fit the data better (i.e., the model with constraints vs. the model without them; Muthén, 2015). The chi-square difference indicated that the coefficients for the cross-lagged paths from science to reading scores were significantly greater than those from reading to science scores, χ^2 (5) = 276.25, $p < .001$. As the result of joint chi-square test was significant, we conducted separate chi-square tests to further identify which pairs of the coefficients were significantly different. The results indicated that all coefficients of the cross-lagged paths from science to reading were significantly greater than those from reading to science ($18.13 < \chi^2$ [1] < 49.99, $p < .001$).

Language Status as a Moderator for the Relation Between Science and Reading (RQ 2)

To answer the second research question (*Does language status influence the relation between domain knowledge and reading throughout the elementary years?*), we examined multi-group RI-CLPM by fitting science and reading scores and covariates to RI-CLPM for each of language groups, categorized by home language (bilingual or monolingual). The multi-group RI-CLPM for each language group explained the data well (CFI = .958, TLI = .933, RMSEA = .038). All coefficients for cross-lagged and autoregressive paths were statistically significant for bilingual and monolingual students (Figure 2). In the model for bilingual students, kindergarten EBRS, English language proficiency, working memory, and cognitive flexibility were significant covariates for all science measures, except for the coefficient of kindergarten cognitive flexibility on kindergarten science measure (see Supplementary File for coefficients of the covariates). In addition, kindergarten EBRS and working memory were significant covariates for all reading measures. Cognitive flexibility (K) was significantly related to first-through third-grade reading, while English language proficiency (K) was to second- and third-grade reading. In the model for monolingual students, all coefficients of the four covariates on reading and science measures were significant, except for the coefficient of English language proficiency on kindergarten reading.To test whether language status influenced the longitudinal

FIGURE 2
Within Components of Multi-Group Random Intercept Cross-Lagged Panel Model (RI-CLPM) for Bilingual and Monolingual Students



Note. N = 9718; all cross-lagged and autoregressive paths were statistically significant at .001 level. Between components and observed variables were omitted in the figure for simplicity. Covariances are shown in Table S2. Coefficients of covariates are shown in Tables S4 and S5.

relation between science and reading scores throughout the elementary years, a chi-square difference test was conducted. First, the coefficients for all paths were constrained to be equal between each model for bilingual and monolingual students. Then, the multi-group RI-CLPM was reanalyzed by freeing the coefficients, and finally chi-square values were compared between the multi-group RI-CLPM with constraints imposed and that without the constraints. The chi-square test indicated that there was no significant difference in the coefficients between bilingual and monolingual students, χ^2 (20) = 25.15, p = .197.

Discussion

The primary goal of this study was to evaluate whether the longitudinal relation between domain knowledge (operationalized as science score) and reading (K-5) is uni- or bidirectional (reciprocal). We achieved this goal using one of the most cutting-edge statistical approaches (RI-CLPM) and a variety of covariates to account for between-individual differences, as well as analyzing a nationally representative longitudinal data that can potentially enhance generalization of findings. In addition, using multi-group RI-CLPM, we were able to examine language status as a potential moderator for the longitudinal relation between domain knowledge and reading. Three major findings emerged. First, the analyses revealed that domain knowledge and reading have a bidirectional relation throughout the elementary years. Second, this longitudinal bidirectional relation was observed in both bilingual and monolingual students, and third, the magnitude of the relation was similar between the two groups.

Longitudinal Reciprocal Relation Between Domain Knowledge and Reading

Study findings are consistent with previous research on the positive role of domain knowledge in reading development (Hwang, 2020; Hwang & Duke, 2020) and the positive role of reading in domain knowledge development (Reed et al., 2017). The study also extends previous findings by demonstrating that domain knowledge and reading *simultaneously* and *longitudinally* support each other throughout the elementary years. This empirical evidence provides support for the notion of a virtuous circle "[where] knowledge begets comprehension, which begets knowledge, and so on" (Duke et al., 2011, p. 53) postulated by many scholars (e.g., Cabell & Hwang, 2020; Cervetti et al., 2012; Kendeou et al., 2016; McNamara & Kintsch, 1996) and consistent with contemporary theoretical models, including the construction-integration model of text comprehension (Kintsch, 1998, 2013) and the Lattice model of reading development (Connor, 2016).

The current findings provide a concrete picture of the nature of the bidirectional relation between domain knowledge and reading. First, even when we controlled for earlier domain knowledge (i.e., autoregressive paths), earlier reading predicted later domain knowledge (i.e., cross-lagged paths). Similarly, when we controlled for earlier reading, earlier domain knowledge predicted later reading. This result might indicate that, regardless of earlier achievement of domain knowledge or reading, the two can facilitate each other throughout the elementary years. Earlier domain knowledge might facilitate later reading development (Hwang, 2020) because domain knowledge can support chunking ideas in text into meaningful semantic categories, which can "free" working memory resources, and therefore facilitate in-depth reading comprehension (e.g., summarizing text, evaluating text; Willingham, 2006). Moreover, domain knowledge can help readers differentiate important ideas from details (Herzmann & Curran, 2011) and support generating inferences of main ideas and missing information in text (McCarthy et al., 2018). Earlier reading might facilitate later domain knowledge because text is a critical means to access information in a domain (Goldman et al., 2016), and good reading skills can support extracting meaning from text (O'Reilly & McNamara, 2007). Particularly, science texts can be challenging as they often include technical vocabulary and have low cohesion (Beck et al., 1991; Graesser et al., 2011). While interacting with challenging texts, skilled readers are likely to notice breakdowns in their comprehension and efficiently leverage reading strategies, which can result in successful reading comprehension and learning (Best et al., 2005; Ozuru et al., 2004). It is also plausible that the observed reciprocal relation is due, in part, to shared cognitive processes between reading comprehension and learning in a domain. For example, in the context of this study in which we operationalized domain knowledge as science domain knowledge, inference-making is likely critical for both reading comprehension and science learning. In reading, students need to make inferences about missing information and important ideas, while in science, they need to make inferences about different types of evidence (e.g., observation, data; Brugar, 2016; Lederman, 2004; Meyer & Crawford, 2011). Efficient inference-making, therefore, can enhance development of both reading and domain knowledge.

Second, coefficients of cross-lagged paths from domain knowledge to reading were greater in magnitude than those from reading to domain knowledge. This asymmetry is a novel finding that warrants further investigation; yet, it preliminarily suggests that the role of domain knowledge may be more integral in reading development than the role of reading in domain knowledge development. During reading, domain knowledge needs to be *continuously* activated to extract and connect idea units from text (establishing local coherence), and to be *simultaneously* integrated with the idea units from the text. In addition, in this study, we operationalized domain knowledge as science domain knowledge. Science domain knowledge is more hierarchically structured than other domains (Neuman & Kaefer, 2018). Having well-structured domain knowledge can facilitate encoding of individual ideas in text into coherent, meaningful units (Newberry et al., 2021), which can enhance text memory and comprehension (Gernsbacher, 1991). Conversely, developing domain knowledge might depend less on reading than reading does on domain knowledge, because students can develop domain knowledge through other means (e.g., various types of media such as instructional videos and inquiry-based activities) in addition to reading (Brugar, 2016; Lederman, 2004; Meyer & Crawford, 2011).

Moderators of the Reciprocal Relation Between Domain Knowledge and Reading

We examined language status as a potential moderator of the longitudinal reciprocal relation between domain knowledge and reading in the elementary years, based on previous research indicating that language status can moderate academic achievement (Hwang & Duke, 2020; Rydland et al., 2012). There were two possibilities—a compensatory mechanism of domain knowledge and a complementary mechanism of being monolingual. If domain knowledge plays a compensating role for relatively low English proficiency and limited exposure to English for bilingual students, stronger cross-lagged paths from domain knowledge to reading would be observed in these students. Alternatively, if language status complements the reciprocal relation between domain knowledge and reading, stronger cross-lagged paths would be observed in students who started school with better English proficiency and more exposure to English (i.e., monolingual students).

We observed that language status (bilingual vs. monolingual) did not moderate the longitudinal reciprocal relation between domain knowledge and reading. That is, we did not identify any compensatory mechanism of domain knowledge or complementary mechanism of being monolingual. All cross-lagged and autoregressive paths were significant in bilingual and monolingual students. Thus, overall, it appears that stronger earlier domain knowledge would lead to stronger later domain knowledge and reading, and stronger earlier reading would lead to stronger later reading and domain knowledge, regardless of language status. This finding is consistent with a longitudinal study by Hwang (2020) that predicted reading growth in the elementary years with early domain knowledge of science and social studies (i.e., general academic knowledge), while accounting for early decoding skills. The current study did not detect any compensatory mechanism of domain knowledge or complementary mechanism of being monolingual. However, this finding is inconsistent with the previous finding by Hwang and Duke (2020) showing that the relation between domain knowledge and reading comprehension was stronger in bilingual than in monolingual students. Hwang and Duke (2020) concluded that domain knowledge might compensate for bilingual students' limited English proficiency.

These mixed results might be attributed in part to the way reading achievement was measured. On the one hand, Hwang and Duke (2020) operationalized reading outcomes as an ordinal variable of which values indicated different *levels* of inference-making (no evidence of comprehension = 0, comprehending words = 1, literal inference = 2, extrapolation = 3, and evaluation = 4). On the other hand, in the present study, reading outcomes were continuous variables in which one score change did not necessarily indicate advancement to higher levels of inference-making. Thus, the compensatory role of domain knowledge might have manifested when domain knowledge was examined in relation to the extent to which students can generate higher levels of inference making, consistent with previous work showing some compensatory role (e.g., Recht & Leslie, 1988). Another possibility is the use of different statistical models. On the one hand, Hwang and Duke (2020) focused on the concurrent relation between domain knowledge and reading comprehension in Grade 3 and did not account for previous reading measures. On the other hand, in the present study, we examined the longitudinal bidirectional relation between domain knowledge and reading in K-5 and accounted for previous domain knowledge and reading measures.

In addition, we did not observe a complementary mechanism for more exposure to English. In other words, monolinguals' reading development did not appear to benefit more from having strong domain knowledge than bilinguals' reading development. Earlier domain knowledge might have facilitated later reading to a similar extent between the two language groups. This finding is inconsistent with the evidence from previous studies showing that bilingual students, unlike monolinguals, have difficulties using their prior knowledge on a topic to make sense of a text on that topic due to their limited English language proficiency (Carrell, 1983; Hudson, 1982). Rydland et al. (2012) also suggested that bilingual students with limited vocabulary depth in second language are likely to encounter challenges in using their topic knowledge to comprehend a text on that topic. The different results between previous and current studies might be partially related to different operationalizations of knowledge and the use of different statistical models. Previous studies operationalized prior knowledge as readers' knowledge specifically related to a topic of a text (i.e., topic knowledge) to concurrently examine reading comprehension on that topic. However, in the present study, we operationalized prior knowledge more broadly as domain knowledge in science and used longitudinal models. Taken together, it may be that domain knowledge supports the trajectory of reading growth (in general) to a similar extent between bilingual and monolingual students, whereas topic knowledge plays a reduced role in facilitating reading comprehension in bilingual students, compared to monolingual students.

Limitations and Future Research

Despite its contributions, this study also has several limitations that need to be addressed in future research. First, domain knowledge was operationalized only with science scores in this study because social studies data were not available. Because science and social studies are often emphasized in the elementary years, future research needs to investigate directionality and magnitude of the relation between domain knowledge in social studies and reading as well. This additional investigation is important given the disciplinary differences between science and social knowledge domains (e.g., science emphasizing procedural knowledge, while history emphasizing recount of events; Shanahan et al., 2011). Second, the present study lacks information about how proximal the topics of texts in the reading assessments are to science domain knowledge because the topics are not disclosed by the ECLS-K. Thus, the results of study should be understood as suggesting the bidirectional relation between science domain knowledge and reading *in general*. Third, among the core components of executive function—working memory, cognitive flexibility, and inhibition—we were not able to include inhibition (i.e., the ability to suppress impulsive, automatic response; Follmer, 2018) as a covariate because it was not assessed in kindergarten. Finally, results of this longitudinal study were based on a variable-centered approach; thus, it is still unknown how profiles of bilingual and monolingual children in terms of reading, domain knowledge, and language learning would change longitudinally throughout the elementary years. Further research addressing heterogeneity of children can help educators better support all children (Kieffer & Christodoulou, 2020).

Implications

The major finding of the study is that domain knowledge and reading appear to be reciprocally related to each other from early grades and throughout the elementary years and the relation is asymmetric with domain knowledge contributing more to reading than reading to domain knowledge. This finding indicates that students need consistent instructional support for developing both domain knowledge and reading from the beginning of schooling.

Specifically, instructional time for content areas to foster domain knowledge and for English language arts (ELA) to support reading needs to be coordinated and integrated. Focusing educational investment on either one, while neglecting the other, would be less effective to support student growth. Currently, however, instructional time in the elementary years is often disproportionately allocated more for ELA at the expense of content-area instruction (Teale et al., 2007; Tyner & Kabourek, 2020).

One way to provide students with support for domain knowledge and reading is by integrating content area and ELA instruction (e.g., Duke et al., 2021; Hwang et al., 2022; Kim et al., 2021; Pearson et al., 2010; see Proctor et al., 2019 for bilingual students). Integrated instruction can be designed in various ways in the elementary years. For example, teachers can support both domain knowledge and reading by selecting and sequencing texts based on content-area standards (e.g., the College, Career, and Civic life [C3] framework for social studies state standards, Next Generation Science Standards [NGSS]; National Council for the Social Studies [NCSS], 2013; NGSS Lead States, 2013) and engaging students in reading, writing, and discussion for the purpose of learning more information in content areas (Hwang et al., 2021, 2022). Also, teaching vocabulary words in relation to the content being taught can foster in-depth vocabulary knowledge and help students understand semantic associations among words and use them in a meaningful context (Neuman & Kaefer, 2018). In addition, students can practice applying different reading strategies meaningfully in the context of knowledge building, which can also foster reading motivation, reading comprehension, and domain knowledge (Guthrie et al., 2004, 2009). Indeed, national standards for ELA and content areas (e.g., CCSS, NGSS, C3) suggested instructional support should connect literacy activities with knowledge building goals (Cervetti & Hiebert, 2019).

Conclusion

In this study, we found evidence for the reciprocal relation between domain knowledge and reading throughout the elementary years in bilingual and monolingual students. The finding suggests that supporting domain knowledge and reading may be crucial in boosting each other. In addition, this study expands reading research by investigating the role of language status as a moderator for the relation between domain knowledge and reading. The finding indicated that there was no difference in the directionality and magnitude of the relation between domain knowledge and reading between bilingual and monolingual students. The finding seems to suggest that supporting both domain knowledge and reading is needed for both language groups from the beginning of schooling.

NOTES

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Supporting Information

Additional supporting information may be found in the online version of this article on the publisher's website:10.1002/rrq.481/suppinfo

Table S1. Covariances in RI-CLPM for All Students.

Table S2. Covariances in Multi-Group RI-CLPM for Bilingual and Monolingual Students.

Table S3. Coefficients of Covariates in All Students RI-CLPM.

Table S4. Coefficients of Covariates in Multi-Group RI-CLPM for Bilingual Students.

Table S5. Coefficients of Covariates in Multi-Group RI-CLPM for Monolingual Students.