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Initial Language Status and Achievement Trajectories Among Hispanic Students: Mediation Through Executive Function

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Initial Language Status and Achievement Trajectories Among Hispanic Students: Mediation Through Executive Function

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSPHY

in Education

by

Wei Wang

Dissertation Committee:
Professor George Farkas, Chair
Professor Deborah Vandell
Professor Young-Suk Kim

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Publications & Presentations

Yang, Yunfan, Huan Wang, Linxiu Zhang, Sean Sylvia, Renfu Luo, Yaojiang Shi, Wei Wang, and Scott Rozelle. "The Han-Minority Achievement Gap, Language, and Returns to Schools in Rural China." Economic Development and Cultural Change 63, no. 2 (2015): 319-359.
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ABSTRACT OF THE DISSERTATION

Initial Language Status and Achievement Trajectories Among Hispanic Students:
Mediation Through Executive Function

By

Wei Wang

Doctor of Philosophy in Education

University of California, Irvine, 2017

Professor George Farkas, Chair

This dissertation systematically estimated the differences in academic achievement trajectories based on children's initial language status at kindergarten entry among Hispanic students. The dissertation also thoroughly tested the hypothesis that the academic advantage of bilingualism is operating through a cognitive channel using mediational analysis in a latent growth model framework. The major findings of this dissertation are as follows: 1. bilingual students with limited English proficiency have a much lower initial level of test scores in all the three subjects than their monolingual peers and thus are particularly in need of future interventions to narrow the initial achievement gaps. 2. lack of English proficiency at kindergarten entry does not hinder language minority students' academic growth rate in reading, math, or science after controlling for family and school characteristics. 3. bilingual English proficient students have faster learning growth rates in reading, math, and science; bilingual students with limited English proficiency have faster growth rates in reading and math but not science. 4. Mediation analyses suggest that the growth rate of working memory mediates the growth rate in academic achievement for both bilingual English proficient and bilingual students with limited English proficiency, and the initial level of working memory and cognitive flexibility mediates the initial gaps between language minority students and monolingual students.

CHAPTER I. Introduction

The rapid growth of the Hispanic[1] population in the United States is one of the most significant current demographic trends in the country. Even more dramatic has been the growth of the school-age Hispanic population. Now accounting for one-sixth of the school-age population, and over one-fifth of public elementary school enrollments, the number of Hispanic students has grown by 150% in the past 20 years (Guzmán & McConnell, 2002). While in some areas there has been improvement in Latino educational performance over the past decade, research has demonstrated that Hispanic students have lower academic achievement than whites and other minority groups beginning in early childhood.

Research on Hispanic achievement emphasizes the role of language status (home language and English proficiency). Lack of fluency in English has been considered a major reason for the long-held finding that Hispanic students exhibit generally poorer academic performance than White children (Glick, Bates, & Yabiku, 2009; Portes & Rumbaut, 2006; Suárez-Orozco, Suárez-Orozco, & Todorova, 2009; Waters & Jimenez, 2005). At the same time, studies also find that bilingual Hispanic students seem to have higher achievement on average than Hispanic students who speak English only (Rumberger & Larson,1998; Reese et. al., 2000; Lutz & Crist, 2009), possibly due to their advanced cognitive skills and cultural capital associated with bilingualism. (e.g., Bialystok, 1988; Bialystok, 2005; Bialystok et al., 2005; Portes & Rumbaut, 2006). While numerous studies have investigated the relationship between language status and children's achievement, past research has yet to answer many important

[1] The terms "Hispanic" and "Latino" are used interchangeably by the U.S. Census Bureau and throughout this paper to identify persons of Mexican, Puerto Rican, Cuban, Central and South American, Dominican, Spanish, and other Hispanic descent; they may be of any race.

questions that can further help us understand the role of language status in early childhood academic achievement among Hispanics.

First, while it is commonly observed that English language learner (ELL) students achieve less than their English proficient counterparts, few studies have examined possible differences in learning trajectories over time depending on Hispanic students' initial language status. We do not know to what extent the academic growth trajectories vary across students' language minority status or initial English proficiency. We also do not know the role of family background and school characteristics in explaining such differences in learning growth trajectories. These questions are important because they will inform how we conceptualize, design, and implement educational programs to serve language minority Hispanic students and Hispanic students with initially limited English proficiency.

When examining the achievement trajectories, two aspects of students' achievement are important to consider. The first is the initial level of academic achievement at kindergarten entry, which is also called school readiness in some literature. Very little research has systematically examined the relationship between language status and achievement at kindergarten entry among Hispanic students. At the same time, a growing body of research suggests that any serious effort to eliminate inequalities at the primary and secondary school levels must also address the school readiness gap—the differences in academic skills among children entering kindergarten (Sadowski, 2006). In fact, kindergarten entry achievement is shown to be strongly predictive of later achievement (e.g., Duncan et. al., 2007). It is thus necessary to compare the school-entry achievement level across monolingual English proficient[2] students, bilingual English proficient (bilingual-EP) students, and bilingual students with limited English proficiency (bilingual-LEP) among Hispanic children so as to understand the link between language status and academic school readiness. Furthermore, previous research consistently shows that at least part of the association between language status and achievement comes from children's socioeconomic background. It is thus important to control for family and school background when examining the relationship between language status and achievement.

The second aspect of the learning trajectory is the growth rate for achievement among Hispanic students. Given the differences of initial language status, students might have different academic achievement growth rates. By using cross-sectional comparisons, previous research studying the trend of the achievement gap between Hispanics and whites fails to account for a possible interaction between explanatory factors (e.g., language status, SES, and school environment) and time (e.g. Reardon & Galindo, 2006; 2009). By examining students of different ethnicities aggregately or focusing on reading achievement only, previous research studying the relationship between language and achievement development either fails to provide credible insights to educational improvement for Hispanics in particular or fails to illuminate how language status might influence academic growth in other content areas (e.g., Kieffer, 2008; Han, 2012). Thus it is important to systematically estimate the possible differences in learning growth rates in multiple subjects by initial language status among Hispanic students. These estimates will help to understand whether students who lag behind at kindergarten entry can catch up to other students via a faster achievement growth rate. These estimates will also inform

[2] The term "proficient" is defined by the cutoff of children's scores on the language proficiency test (preLAS) administered to children in the dataset to determine whether a student should be screened to receive assessments in Spanish or English. Please see more detailed description in the methodology section of this proposal.

the design of future interventions to narrow the initial achievement gap through promoting the growth rate of language minority students or students with limited English proficiency.

Finally, in terms of understanding the mechanisms through which initial language status is related to achievement trajectories, past research has proposed various hypotheses to explain the difference in learning outcomes by different language status, however, studies have yet to identify whether these hypotheses are supported by empirical data. Specifically, research has proposed that bilingual students might have an academic advantage over monolingual students because of cognitive benefits associated with bilingualism (Bialystok, 1988, 2005; Duncan and De Avilla, 1979; Lindholm and Aclan, 1991; Willig, 1985; Secada, 1991; Umbel & Oller, 1994). However, few research studies have formally tested the mediational role of cognitive skills, for example, cognitive flexibility and working memory, in the relationship between language status and academic growth trajectory. The mediational analyses are necessary because they will provide us further insights to understand the relationships involving the three constructs—bilingual experiences, executive function, and academic achievement.

To address these main gaps in the literature, the current study uses nationally representative longitudinal data to study and explain the differential academic development trajectories of three subpopulations of Hispanic students: (a) English proficient speakers from English speaking homes (monolingual English proficient students), (b) students who speak Spanish at home and enter kindergarten with initially limited English proficiency (Bilingual-LEP), and (c) Hispanic students who speak Spanish at home and enter kindergarten with full English proficiency (Bilingual-EP). In estimating the relationship between initial language status and later academic growth trajectories, I control for family background and school characteristics to examine the extent to which family and school explain the differences in academic growth.

Finally, I tested the extent to which the relationship between bilingualism and academic growth is mediated through the development of cognitive skills within a longitudinal mediational analysis framework.

Taken together, the analyses in this dissertation extend previous research on the relationship between initial language status and academic growth in three ways. First, the analyses distinguish language proficiency and bilingual status by including three groups of students in the analysis (students speaking Spanish but also have full proficiency in English, students speaking Spanish but have only limited proficiency in English, and students speaking only English). Second, these studies describe the learning trajectories of each of these groups in three academic subjects (reading, math, and science) so as to cover a comprehensive content area to understand students' academic achievement. Finally, the analyses thoroughly test the hypothesis that the academic advantage of bilingualism is operating through a cognitive channel using mediational analysis in a latent growth model framework.

The major findings of this dissertation are as follows: 1. bilingual LEP students have a much lower initial level of test scores in all the three subjects than their monolingual peers and thus are particularly in need of future interventions to narrow the initial achievement gaps. 2. lack of English proficiency at kindergarten entry does not hinder language minority students' academic growth rate in reading, math, or science after controlling for family and school characteristics. 3. bilingual EP students have faster learning growth rates in reading, math, and science; bilingual LEP students have faster growth rates in reading and math but not science. 4. Mediation analyses suggest that the growth rate of working memory mediates the growth rate in academic achievement for both bilingual EP and bilingual LEP students, and the initial level of working memory and cognitive flexibility mediates the initial gaps between language minority students and monolingual students.

CHAPTER II. Literature Review

2.1 The Relationship Between Language Status and Academic Achievement

2.1.1 language status and academic achievement at kindergarten entry

The literature on English Language Learners (ELL) in American schools has emphasized the role of English proficiency in benefiting achievement (for a review, see Genesee, 2006) and thus cited the limited English proficiency among language minority Hispanics as one important challenge in the education of Hispanic students. Prior research on Hispanic achievement has also found a correlation between English proficiency and achievement among Hispanics (e.g., So & Chan, 1984; Bradby, 1992). Furthermore, research on immigrants has consistently shown that English proficiency is strongly associated with better academic outcomes for children and adolescents (Glick, Bates, & Yabiku, 2009; Greenman & Xie, 2008; Portes & Rumbaut, 2006; Suárez-Orozco, Suárez-Orozco, & Todorova, 2008; Waters & Jimenez, 2005). More specifically, lack of English proficiency negatively predicts the academic achievement at kindergarten entry (Magnuson et al., 2006). Thus, past research shows consistent evidence that lack of English proficiency is correlated with lower academic achievement at kindergarten entry.

Few studies have formally examined the role of speaking two languages (both Spanish and English) in predicting academic achievement at kindergarten entry. At the same time, however, research on bilingualism (e.g., Golash-Boza, 2005; Portes & Hao, 1998; 2002; 2004) has provided abundant evidence that bilingual students seem to have higher achievement than Hispanic students who speak English only. Previous studies also found specific evidence that bilingual students outperform their monolingual peers in math achievement even though the monolingual students attended schools that had many more teaching resources (Clarkson, 1992). Furthermore, research has found evidence that bilingual students might be more advantaged than monolingual students in academic outcomes for two possible reasons. The first possibility is that they have the English-language skills to function effectively in school without abandoning their Spanish language and culture, which enables them to maintain an identity and to function effectively in their families and communities. (Portes and Rumbaut, 2001; Pacini-Ketchabaw et al., 2001; Buriel et al., 1998). Alternatively, this could be due to the benefits in cognitive development associated with bilingualism (Adesope et. al., 2010). More recent empirical work, however, found that even though bilingualism shows some benefits in academic achievement growth, multilingual students have lower academic outcomes starting at kindergarten than their monolingual peers (Han, 2011).

Taken together, past research shows consistent evidence that lack of English proficiency is negatively correlated with academic achievement at kindergarten entry; past research shows mixed evidence in terms of whether bilingual Hispanic students outperform monolingual Hispanics in academic achievement starting at kindergarten. More specifically, while many research studies found evidence of benefits of bilingualism on academic outcomes, it is not clear in which way and at what time the benefits will be present. For example, it is not clear whether the advantage starts to be present at or before kindergarten or any time in the elementary school years. It is also not clear whether the advantage of bilingualism will exhibit in the form of a higher level of cross-sectional achievement at a certain time or in the form of a faster academic growth rate over a certain time, compared to that of monolingual students. Finally, past research did not help us accurately define the concept of being “bilingual”. Clearly, “bilingual” can refer to a broad case when a Hispanic student speaks both Spanish and English, but past research does not further specify whether or how the proficiency of each language might make a difference in the relationship between language status and academic achievement.

2.1.2 Difference in learning trajectories between LEP students and native English speakers

Compared to native English speakers, Bilingual-LEP Hispanic children lack the English proficiency to gain full access to mainstream instruction without support (August & Shanahan, 2006). Previous research has proposed two developmental hypotheses regarding the differences in learning trajectory based on differences in children's initial English proficiency. A "differential skills" hypothesis posits that, because children with limited English proficiency enter schools at greater risk (for example, they are less school ready than their native English speaker peers), and cannot access sufficient learning opportunities and resources in schools, they will have slower reading growth rate than their English proficient counterparts (Chall, 1983; RAND Reading Study Group, 2002). A developmental lag hypothesis posits that, since Hispanic children with limited English proficiency are immersed in an English environment in U.S. schools and might be served by various English-learning programs, they will catch up with their English proficient counterparts in reading achievement trajectory given enough time (Collier, 1989; Hakuta, Butler, & Witt, 2000).

Generally, prior quantitative studies support the "differential skills" hypothesis. Cross sectional studies generally found that LEP students have lower academic skills in early elementary years. For example, in a systematic review, the National Literacy Panel on Language Minority Children and Youth found that language minority learners have lower achievement on the reading comprehension tasks (Lesaux, Koda, Siegel, & Shanahan, 2006). Furthermore, studies employing a longitudinal design also found LEP students have deficiencies in various aspects of oral language skills in English—such as vocabulary, syntactic awareness, and verbal working memory—that may predict future difficulties in English reading comprehension

(Verhoeven, 2000; Chiappe, Siegel, & Wade-Woolley, 2002). Estimating a growth model for language minority students compared to native English speakers, Kieffer (2008) found that the reading trajectory of language minority learners entering kindergarten with limited English proficiency diverges from that of native English speakers, yielding larger differences in achievement by the fifth grade compared to the gap at kindergarten. Similarly, Han (2012) also found that Latino language minority children with limited English proficiency have a slower growth rate in reading score than that of White English monolingual children.

2.1.3 Difference in learning trajectories between bilingual students and monolingual students

In terms of the possible differences in growth trajectories between Bilingual-EP students and native English speakers, past research has yet to formally propose any developmental hypothesis. However, prior studies show strong and consistent evidence of the benefits of bilingualism in academic achievement. Specifically, prior research has found a positive relationship between bilingual fluency and various outcomes such as higher math and reading scores (Golash-Boza, 2005; Portes & Hao, 1998, 2002, 2004; Portes & Schauffler, 1994). Scholars have generally explained bilingualism's positive effects through its relation to greater cognitive flexibility and abstract thinking skills (Bialystok, 1988; Rumbaut, 1995) as well as through the access that bilingual children have to positive ''cultural capital'' in their families and ethnic communities (Bankston & Zhou, 1995; Portes & Rumbaut, 2006; Portes & Zhou, 1993; Rumberger & Larson, 1998; Stanton-Salazar & Dornbusch, 1995).

Additionally, many studies have shown the successful use of bilingual education to promote ELL students' academic performance (Christian, Howard, & Loeb, 2000; Christian, Montone, Lindholm, & Carranza, 1997; Collier & Thomas, 2004; Lindholm-Leary, 2001). For example, Collier and Thomas (2004) found that children who received strong, grade-level cognitive and academic support in both their first and second languages for many years were able to achieve as well as, if not better than, their Native-English-speaking (NES) peers. In contrast, the achievement gap between ELL students in segregated, remedial programs, and their Native-English-speaking peers widened. Stipek, Ryan, and Alarcon (2001) also found that bilingually schooled students, after four to seven years of such instruction, outperformed in all subjects their NES peers who were educated solely in English. These studies also found suggestive evidence that developing biliteracy tends to help ELL students attain a faster academic growth rate, so that they can narrow and eventually close their initial academic gap with NES students.

Combining the evidence from correlational research that documents the cognitive and sociocultural benefits of bilingualism, and the causal evaluation of bilingual instruction that documents the positive effects of bilingualism on academic achievement, one would expect that bilingual Hispanic students would have a faster learning growth rate than their monolingual counterparts because of the associated advantage. Consistent with this hypothesis, Han (2012) found that bilingual Hispanic students show a faster growth rate in both reading and math than their white monolingual peers and the advantage of bilingualism in math growth is even larger than that for the reading growth. Han (2012) did not estimate the role of language status on science achievement trajectories, nor did any other studies.

2.1.4 The confounding role of socioeconomic status

Prior research on early childhood academic outcomes documented that various family characteristics have important effects on the differential academic achievement of children.

Among the many demographic factors that could influence children's academic achievement, family socioeconomic status (SES), a composite of family income, parental education and occupation, is well-established as the strongest factor in child development (Crosnoe, 2007). SES plays an important role in nurturing children's academic outcomes in general and among Hispanic children in particular: research on Hispanic achievement has found that differences in SES helped explain the large gap between Hispanics and whites. Hispanic families, as a group, on average have a lower SES compared to white families. Nonetheless, even when studies control for SES, a significant association between language status and academic performance is still observed (Fuligni, 1997; Kao & Tienda, 1998; Reardon & Galindo, 2009; Rumbaut, 1997; Sirin, 2005).

At the same time, family SES also influences children's language development and thus influences the children's language status at kindergarten entry. Researchers have found that children from low-SES backgrounds are less likely to be proficient in English. Reese et al. (2000) found that parents' SES and family literacy practices significantly predicted later English reading. Lindholm-Leary and Hernandez (2011) found parental education significantly predicts English proficiency among Spanish speakers. A review by Hoff (2013) suggests that family SES can determine the character and amount of the children's early language experience, which then influence children's proficiency in English. For example, research demonstrated that SES can influence the way parents interact with children in the home (Bowey, 1995; Dickinson & Tabors, 2001; Hammer et al., 2003), and such interactions can in turn have significant effects on children's English proficiency skills (e.g., Dickinson & Porche, 2011). Family engagement in early care and education settings may play a role in the rate of English acquisition (Hernandez, Denton, & Macartney, 2007; Lopez & Cole, 1999; Naughton, 2004). Magnuson, Lahaie, and

Waldfogel (2006) found that attending preschool raises the English-language proficiency of children of immigrants. Researchers have found that ELL children, and Latino children in particular, are less likely to be enrolled in formal preschool programs than their peers (Matthews & Ewen, 2006), which is possibly a reflection of socioeconomic disadvantage and lack of access to affordable center-based care (Hernandez et al., 2007). Thus, family SES and the resulting home environment are likely to influence children's language development and hence influence their language status at kindergarten entry. Because family background is correlated with both language status itself and later academic achievement, it is important to control for these family characteristics when estimating the relationship between language status and academic achievement.

2.1.5 The confounding role of school characteristics

Past research has also identified several school factors—in addition to initial English proficiency and family SES—that are associated with students' learning trajectories and academic achievement, including school social class and race/ethnic composition, and the school learning environment (for a review, see Snow, Burns, & Griffin, 1998). Because Hispanic students in the U.S. are more likely to be poor, and to attend highly segregated schools (Capps, Fix, Murray, Ost, Passel, & Herwantoro, 2005; Cosentino de Cohen, Deterding, & Clewell, 2005; Galindo & Reardon, 2006), and bilingual Hispanic students might interact with the school environment in a way that is different from monolingual Hispanics, it is very important to disentangle the school factors in examining the possible differences in achievement trajectories by language status. In fact, Han (2012) found that school-level factors explain a third of the reduction in the achievement differences between bilingual children and their white monolingual peers from kindergarten to the fifth grade.

Additionally, research found that schools characterized by positive learning environments (those that emphasize the quality of academic instruction and promote positive social relations between teachers and students) and good physical facilities benefit students' learning (Borman & Overman, 2004; Pianta, Stuhlman, & Hamre, 2002; Rutter & Maughan, 2002). More specifically, several aspects of school environments are documented as most strongly associated with student academic achievement (e.g., Han, 2012): a material environment characterized by adequate teaching materials, physical facilities, and funding; a learning environment distinguished by the high quality of academic instruction, high expectations for students, positive social relationships between teachers and students; and a supportive teaching environment characterized by strong leadership that communicates a clear mission and shared vision with teachers and staff.

Furthermore, studies have documented that the composition of the students in a school (Borman & Overman, 2004; Garcıa Coll & Szalacha, 2004; Rutter & Maughan, 2002) might have important influence on achievement growth. Indeed, schools with high percentages of native-born, White, middle- to upper-class students tend to have higher overall academic performance (Borman & Overman, 2004; Crosnoe, 2005). Research also found that achievement among the non-white student population increases, on average, with racial integration (Bankston & Caldas, 1996; Roscigno, 1998). More recent research (Rumberger & Palardy, 2005; Ryabov & Van Hook, 2007) found that the socioeconomic composition of the school significantly predicts Hispanic achievement. Research shows Hispanics are increasingly more segregated from white students among immigrant groups (Reardon, 2015; Logan, Stowell, & Oakley, 2002; Orfield &

Yun, 1999) and are likely to attend schools with a high concentration of English non-proficient and poor students (Logan, Stowell, & Oakley, 2002; Schmid, 2001; Van Hook & Stamper Balistreri, 2002). Using the ECLS-K: 1998 dataset, Galindo and Reardon (2006) also documented that compared to whites, Hispanic students attend larger schools with a higher concentration of Hispanic and Limited English Proficiency (LEP) students. Thus, school composition is likely to pose particular challenges for the learning outcomes and growth for Hispanic language minority students.

Taken together, characteristics such as school facilities, school composition, and the overall learning environment likely shape the learning trajectories of Hispanic students. Thus, it is important to control for these school characteristics when trying to identify the effects of language status on Hispanic learning trajectories.

2.2. Executive Function as a Potential Mediator

In terms of the mechanisms through which bilingualism benefits academic achievement, past research has indicated conceptualizations in at least two strands. The first strand is called "the cognitive channel", which states that bilingual students have greater cognitive flexibility, abstract thinking skills, and working memory (Bialystok, 1988, 2005; Duncan and De Avilla, 1979; Lindholm and Aclan, 1991; Willig, 1985; Secada, 1991; Umbel & Oller, 1994), which then contribute to an academic advantage in test scores. The second mechanism is called "the cultural channel", which states that bilingual children gain an academic advantage through their access to positive ‘‘cultural capital’’ in their families and ethnic communities (Bankston & Zhou, 1995; Portes & Rumbaut, 2006; Portes & Zhou, 1993; Rumberger & Larson, 1998; Stanton-

Salazar & Dornbusch, 1995). Because this dissertation focuses on testing the cognitive channel in bilingual students, I am only reviewing studies related to the "cognitive channel" here.

2.2.1 Cognitive correlates of bilingualism

Peal and Lambert (1962) first found that bilingual participants outperformed monolinguals on several verbal and nonverbal intelligence measures. Since then, a large portion of research has accumulated evidence indicating that bilingualism is associated with a number of cognitive benefits. Among the many cognitive measures associated with bilingualism that have been studied, two measures will be reviewed in detail here as they are most closely related to this dissertation – attentional control or cognitive flexibility, and working memory.

It is worth noting that while attentional control and cognitive flexibility might have appeared as different concepts and cognitive measures in some studies, in the review here, I referred to them as similar to each other when studies measured both of them by the Dimensional Change Card Sort (DCCS) task. For example, a great number of studies have found evidence that bilingual students have great cognitive flexibility (Hakuta, 1990; Iannaccone, Fraternali, & Vaccia, 1992; Kovac & Teglas, 2002; Kozulin, 1999). At the same time, there is considerable evidence that bilingual speakers are more readily able to control their attention compared to their monolingual peers (Bialystok, 1999; 2006; Bialystok, Craik, & Ryan, 2006; Bialystok & Martin, 2004). In these cited studies, both the attentional control/focus and the cognitive flexibility are measured by the DCCS task items. Researchers have also proposed theories explaining the correlation between bilingualism and this cognitive advantage. A dominant explanation (Bialystok, 2001a; Bialystok, Martin, & Viswanathan, 2005; Yoshida, 2008) states that the regular use of two different languages requires bilinguals to control their attention in a more advanced way: bilinguals need to selectively attend to different representations, to concurrently hold two languages in the mind, and to resist intrusions of words and grammar from one language into the other. This may be responsible for the greater attentional control or cognitive flexibility reflected by improved performance on tasks with conflicting or distracting information.

Studies have also extensively examined the relationship between bilingualism and working memory. Indeed, past research has proposed at least two competing hypotheses regarding the relationship between bilingualism and working memory. First, the need to manage two languages concurrently could place greater demands on working memory. This might result in the case that speaking two languages impedes efficient processing of information in working memory because of the extra cognitive load imposed on working memory (e.g., Lee, Plass, & Homer, 2006; Sweller & Chandler, 1994; van Merrienboer & Sweller, 2005). In contrast, bilinguals' well-developed ability to selectively choose one representation instead of the other based on specific contexts, may increase the efficiency of their working memory capacity because working memory resources are properly managed through such inhibitory processing (Bialystok et al., 2004; Bialystok, Craik, & Luk 2008; Fernandes, Craik, Bialystok, & Kreuger, 2007; Just & Carpenter, 1992; Michael & Gollan, 2005; Rosen & Engle, 1997). Empirical research has generally found evidence supporting the latter hypothesis. For example, Humphreys and Mumtaz (2001) found that bilingualism is significantly associated with higher working memory. Abu-Rabia and Siegel (2002) found similar results for elementary children who speak both Arabic and English. Bialystok (2006) also found a significantly positive effect of bilingualism on working memory. Indeed, in the meta-analysis (Adesope et. al., 2010) that summarized seven studies (all of the studies had an experimental group of bilingual participants who are equally proficient in both languages and a control group of monolingual participants) on the relationship between bilingualism and working memory, the average weighted size of effects of bilingualism on working memory is 0.48 with a standard error of 0.10.

Taken together, past studies have documented consistent evidence that bilingualism is positively correlated with various cognitive skills (Bialystok, 1988, 2005; Duncan and De Avilla, 1979; Lindholm and Aclan, 1991; Willig, 1985; Hakuta, 1984;1987; Secada, 1991; Umbel & Oller, 1994). A recent review by Adesope et al. (2010) indicates that past research is consistent in showing bilingualism is reliably associated with increased attentional control and working memory. More specifically, because the meta-analysis includes only studies that have an experimental group of bilingual participants and a control group of monolingual participants, it provides systematic and rigorous estimates of the effect of bilingualism. According to these studies, fluent bilingual speakers have a cognitive advantage because they have two codes for every concept, which leads to greater cognitive flexibility and better working memory capacity; this benefit on cognitive development, net of socioeconomic or sociocultural factors, might ultimately contribute to the development of academic achievement.

2.2.2 Executive function and academic achievement

A large body of research has examined the relationship between executive function and academic achievement, among which most has studied the predictive role of working memory in specific academic subjects, including math, reading, and science. Using growth curve analyses, Bull and colleagues (2008) found that executive function skills predicted learning in general; more specifically, they found that working memory predicts math achievement for children in their early school years. In a recent review, Raghubar et. al. (2010) suggested that working memory, which involves controlling, regulating, and actively maintaining relevant information to accomplish complex cognitive tasks, has important influences on both cross-sectional math achievement and math achievement growth in longitudinal contexts. More specifically, by summarizing past studies examining the link between working memory and academic achievement, they concluded that research has provided consistent evidence that working memory is predictive of math performance across preschool and elementary years; the growth of working memory is also significantly related to the growth of math achievement in the longitudinal framework. A more recent work (Duncan et. al., 2016) also found strong associations between executive function and math achievement, and thus further strengthened empirical evidence of the potential for executive function interventions to transfer to mathematics achievement.

At the same time, studies have also found evidence that working memory is positively correlated with reading skills. For example, Mozzoco and Kover (2007) found that working memory and other executive function measures are correlated with both math and reading achievement among children at first, third, and fifth grade. Clair-Thompson and Gathercole (2006) examined the relationship between working memory and achievement in reading, math, and science and they also found that working memory is significantly correlated with higher performance in reading. Swanson and Howell (2001) found that working memory significantly predicted elementary students' word recognition skills and reading comprehension performance. Taken together, while the relationship between working memory and reading performance has not been studied as extensively as that for math performance, past research generally provided consistent evidence that working memory also positively predicts reading performance. Studies examining the relationship between working memory and science achievement are relatively scarce. Among the very few studies, Clair-Thompson and Gathercole (2006) found that working memory and other executive function measures are also predictive of science performance.

Compared to the vast majority of studies that examined the predictive role of working memory in academic achievement, the predictive role of cognitive flexibility or attentional control in academic achievement is less studied. As mentioned earlier, previous studies might use various names to describe the underlying skills measured by the DCCS task, thus here I review studies that have examined the predictive role of the DCCS task performance in academic achievement, regardless of the exact names describing the underlying executive function skills. In general, the DCCS task measures the capacity to shift and sustain attention. This capacity fosters learning by allowing children to strategically focus and disengage attention, maintain concentration, resist interference, and ignore distractions (Posner & Petersen, 1990; Rothbart, Posner, & Hershey, 1995). Enhanced attentional flexibility helps with the regulation of arousal and the maintenance of information in working memory (Chang & Burns, 2005; Derryberry & Rothbart, 1997). Bierman and colleagues (2008) found that the DCCS task performance predicted significant gains in reading skills before kindergarten. Coldren (2013) also found that students' performance in the DCCS task significantly predicted their math scores and other school-based achievement test scores at kindergarten. Colé, Duncan, and Blaye (2014) found that cognitive flexibility measured by sorting tasks that are similar to the DCCS task significantly predicts early reading skills. While these studies used correlational methods and only controlled for a limited set of confounding variables, together they provided a consistent picture in which cognitive flexibility is positively associated with academic achievement in early childhood.

2.2.3 Executive function mediates the relationship between bilingualism and achievement

While past research has established a robust linkage between bilingualism and executive function measured by cognitive flexibility and working memory, as well as the linkage between executive function and academic achievement measured by test scores, no studies, to my knowledge, have systematically tested the mediation path involving the three constructs. More specifically, the mediational path refers to a relationship in which executive function mediates the effect of bilingualism on academic achievement, in both a cross-sectional and a longitudinal framework. Because of the lack of systematic examination of this mediational path in the past research, the review here focuses on the theoretical foundations pointing to this mediational path.

At least three strands of research evidence help to lay out this mediational path. First, as reviewed above, past studies have provided consistent and rich evidence that the correlation between bilingualism and executive function is robust. While these studies are mostly observational and did not provide strictly causal estimates, neurobiological research has studied the possible mechanisms of these correlations and provided relatively clear evidence and framework in attesting to this relationship. For example, neuroscience research found that bilingualism profoundly affects the brain, yielding functional and structural changes in cortical regions dedicated to language processing and executive function (Crinion J, et al, 2006; Kim KHS, et al.,1997). In addition, Stocco and colleagues (2012) have proposed a neurobiological framework in which bilingual experience may “train the brain,” enabling improved performance under conditions of competitive information selection during information transfer, thus improving executive function. These studies further strengthened the relationship between bilingual experiences and development of executive function.

Second, research has also proposed convergent evidence indicating that the predictive role of executive function in academic achievement is not merely a correlation. Alloway and Alloway (2010) have found that working memory skills are strong predictors of literacy and numeracy independent of IQ, which demonstrates that working memory is not a proxy for IQ but rather represents a separable cognitive skill with unique links to academic achievement. Conversely, research has found evidence that working memory deficits may underlie learning difficulties experienced by children (Aronen et. al., 2004; Martinussen, et. al., 2005; Ashcraft & Kirk, 2001). Moreover, a recent review (Titz & Karbach, 2014) summarizing past studies on working memory and executive function training interventions suggested there are positive effects of process-based working-memory training on academic achievement, particularly in the domain of reading (e.g., Loosli et. al., 2012). They also found that the transfer of training occurred in children suffering from cognitive and academic deficits as well as in healthy students. This evidence adds up to a strong indication that working memory and other executive function measures could be causally effective in academic achievement.

Finally, the positive effect of bilingual experience on academic achievement may be causal. As reviewed above, past research shows strong and consistent evidence on the benefits of bilingualism in academic achievement. More importantly, many causal evaluation studies of bilingual instruction and training found positive effects of bilingual education. For example, the educational outcomes of bilingually educated students, especially in two-way immersion programs, were at least comparable to, and usually higher than, their comparison peers (e.g., Burnham-Massey & Piña, 1990; Greene, 1997). In addition, bilingual programs with a more focused goal to developing biliteracy—such as dual immersion programs—have significant positive effects on academic outcomes (Thomas & Collier, 2002). A more recent study

(Valentino & Reardon, 2015) found that test score growth rates of ELs in bilingual programs exceeded growth rates for ELs in English-only classrooms. This evidence, combined with the correlational studies that support the correlation between bilingualism and achievement, points to the potential of a causal relationship between bilingual experiences and academic achievement.

The evidence summarized above suggests that what is currently lacking in the field is a systematically comprehensive model that tests the mediational role of executive function in the relationship between bilingualism and academic achievement. I believe such formal testing will inform what we currently know about the relationships involving the three main constructs. It will also provide the basis from which to guide further discoveries devoted to understanding the cognitive benefits of bilingualism and to potentially inform practice.

CHAPTER III. Research Questions and Hypotheses

My research questions are as follows:

1. What are the differences in learning trajectories among the three groups of students (monolingual, bilingual English Proficient (EP), and bilingual students with limited English Proficiency(LEP))?

Hypothesis 1: Compared to monolingual Hispanic students, bilingual EP and bilingual LEP students will have lower initial test scores starting from kindergarten entry. At least part of the gaps in test scores between language minority students and monolingual students at kindergarten entry will be explained by family background and school characteristics.

Hypothesis 2: In terms of growth rate, bilingual EP Hispanic children will have a faster learning growth rate than their monolingual counterparts due to the academic advantage associated with bilingualism; bilingual LEP Hispanic children will have a slower learning growth rate than their native English speaking peers (consistent with the "differential skills" hypothesis).

2. To what extent is the effect of initial language status on students' academic achievement trajectory mediated by students' development of executive function?

Hypothesis 3: At least part of the differences in the initial level of test scores will be mediated by the initial differences in cognitive flexibility and working memory. In other words, the lower level of cognitive flexibility and working memory will contribute to the lower level of test scores at kindergarten entry.

Hypothesis 4: The growth rate of working memory will mediate the relationship between language status and the growth rate of academic achievement. If bilingual English proficient

(EP) students have a faster growth rate in working memory, then this faster growth rate of working memory will contribute to the faster growth rate in test scores.

CHAPTER IV. Methodology

4.1 Dataset and Participants

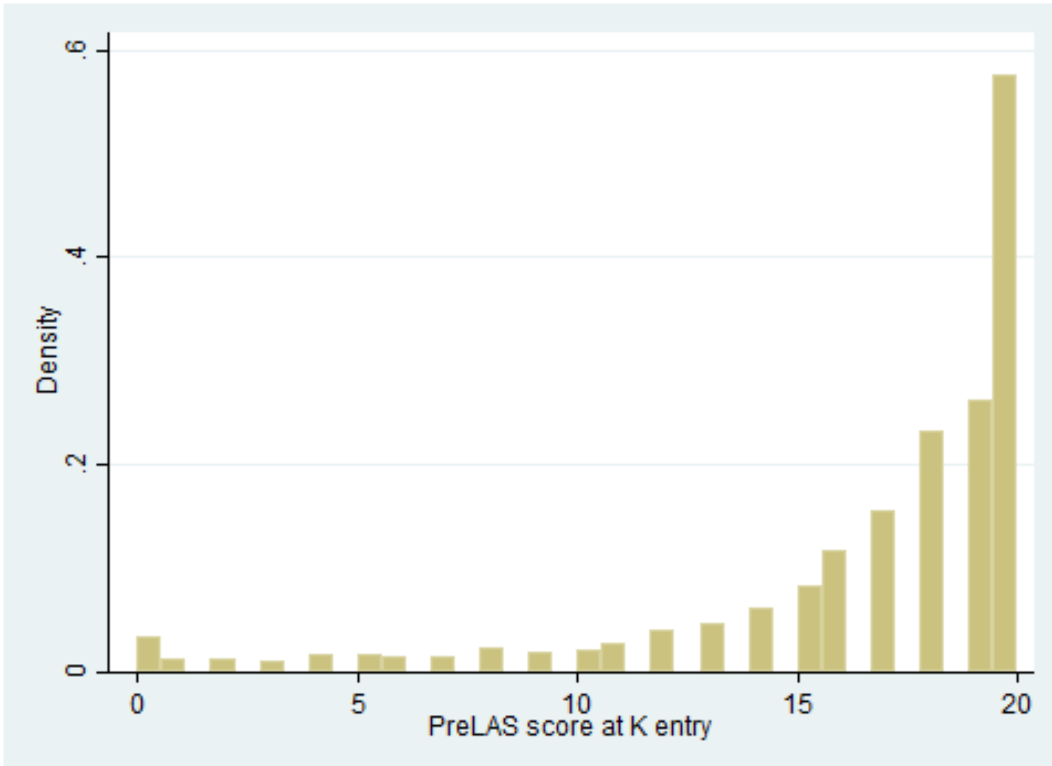
The Early Childhood Longitudinal Study-Kindergarten: 2011 (ECLS-K: 2011) is an ongoing study conducted by the National Center for Education Statistics (NCES). The study is nationally representative of students attending kindergarten during the 2010-2011 school year, tracking them from kindergarten through fifth grade. At the time of the analysis, data were available from kindergarten to the 3rd grade. Data collection included parent phone interviews, teacher and principal questionnaires, and direct child cognitive assessments in math, reading, science, and executive functioning.

The ECLS-K: 2011 dataset contains 17064 students in total, among which 4585 students are identified as Hispanic students. 3716 students have non-missing values in their language status indicator variables (whether speak Spanish in home, and whether proficient in English at kindergarten entry), which constitutes the analysis sample for the study. A questionnaire was administered to parents in which they were asked whether the family speaks a language other than English in the home as the primary language. I used this variable[2] to create categories of monolingual speakers (English only) and bilingual speakers (English and Spanish). In addition, all children at kindergarten entry were administered an English proficiency test called the Preschool Language Assessment Scale (preLAS 2000) test to diagnose whether a child is proficient enough in English to receive assessments given in English. The test consisted of two tasks. The "Simon Says" task required children to follow simple, direct instructions given by the assessor in English. The "Art Show" task was a picture vocabulary assessment that tested children's expressive vocabulary. A raw number-right score is provided for children's

[2] Parents who reported cannot decide which language are primarily spoken is identified as bilingual speakers.

performance on the set of 20 English basic reading skills (EBRS) items. The EBRS items target specific early reading skills, predominantly letter recognition and letter sounds, with a few phonemic awareness, vocabulary, and word reading items. These items were administered to all children as part of the reading assessment routing test in kindergarten. The score of preLAS is more appropriate in diagnosing whether a student is English proficient than reflecting the specific English proficiency level of each student. The histogram of preLAS scores for all students in the analysis sample is shown in Figure 1. As shown in the figure, more than 50% of students attained a full score of 20, indicating that they are fully proficient in English. I used a cutoff of 16 points recommended by the assessment designers (Tourangeau. et al., 2012) to create two distinctive categories of English proficient children and English non-proficient children. By cross matching the indicator of home language and English proficiency, I created four categories of language status among Hispanic children at kindergarten entry: 1773 students are monolingual English proficient (Monolingual-EP), 1107 students are Bilingual English proficient (Bilingual-EP), 836 students are Bilingual English non-Proficient (Bilingual-LEP), and 117 students are monolingual English non-proficient (Monolingual-LEP). I dropped the 117 Monolingual-LEP students and kept only three categories for the analysis. Monolingual English proficient (Monolingual-EP) is treated as the reference group in my analysis in the study.

Figure 1
The histogram of preLAS test scores for Hispanic students at kindergarten entry



4.2 Measurements

4.2.1 Achievement/Test Score Measures

I used the reading, math, and science IRT scale score to measure students' academic achievement. These assessments were given to children in fall kindergarten, spring kindergarten, fall 1st grade, spring 1st grade, fall 2nd grade, spring 2nd grade, and spring 3rd grade. The exception was the science assessment, which was not administered until the spring of kindergarten. According to the ECLS-K: 2011 user manual (Tourangeau. Et. al., 2012), the IRT-based scale scores are overall measures of achievement, and they are appropriate for both cross-sectional and longitudinal analyses – "They are useful in examining differences in overall achievement among subgroups of children in a given data collection round or in different rounds, as well as in analysis looking at correlations between achievement and child, family, and school characteristics." For the IRT-based scores, the reliability of the scale score ranges from .75 to .99 for reading, mathematics, and science. The direct cognitive assessments in reading, mathematics, and science are individually administered, two-stage adaptive tests. Because children were asked different questions depending on the answers they provided to the initial questions on the test, IRT adjusted scale scores are preferable to simple test measures reflecting only the number of correct answers.

4.2.2 Executive Function Measures

The ECLS-K: 2011 measures children's executive functions: "executive functions are interdependent processes that work together to regulate and orchestrate cognition, emotion, and behavior and that help a child to learn in the classroom." Specifically, the Dimensional Change Card Sort (Zelazo, 2006) is used to assess children's cognitive flexibility, and working memory is assessed by the Numbers Reversed subtest of the Woodcock-Johnson III (WJ III) Tests of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001). Based on the recommendations for the assessment developer, I used the overall score (scale from 0 to 18) of the Dimensional Change Card Sort task to indicate the general performance in cognitive flexibility, and used the w score (scale from 393 to 604) of the Numbers Reversed task to make comparisons in the growth of working memory among children in different groups.

It is worth noting that different versions of the DCCS were used in different rounds of data collection in ECLS-K because there was no single task that was age appropriate across all rounds of data collection when the study began. During the kindergarten and 1st grade rounds, the hard-copy or physical version of the DCCS was administered using cards that children were asked to sort into piles. In the version of the DCCS task used in kindergarten and 1st grade, children were asked to sort a series of 22 picture cards according to different rules. Each card had a picture of either a red rabbit or a blue boat. The children were asked to sort each card into one of two trays depending on the sorting rule they had been told to use (e.g., by color (i.e., red or blue), by shape (i.e., rabbit or boat)). Beginning in the fall 2nd-grade round children were administered a new, age-appropriate, computerized version of the DCCS in which the "cards" are presented on a computer screen and children sort them into "piles" on the computer screen using keys on the keyboard to indicate where to place each card. Although the physical and the computer versions assess the same construct, the scoring and the way in which the construct is assessed differ across the two tasks. Therefore, the DCCS scores provided in the ECLS-K are not appropriate for comparison across different time points. Thus, this study did not attempt to estimate the growth of cognitive flexibility across time. Instead, analyses in this dissertation only investigated the cognitive flexibility at the kindergarten entry level.

According to ECLS-K , the Numbers Reversed task assesses the child's working memory. It is a backward digit span task that requires the child to repeat an orally presented sequence of numbers in the reverse order in which the numbers are presented. For example, if presented with the sequence "3...5," the child would be expected to say "5...3." Children are given 5 two-number sequences. If the child gets three consecutive two-number sequences incorrect, then the Numbers Reversed task ends. If the child does not get three consecutive two-number sequences incorrect, the child is then given 5 three-number sequences. The sequence becomes increasingly longer, up to a maximum of eight numbers, until the child gets three consecutive number sequences incorrect or completes all number sequences. The maximum number of items any child could have been administered in all data collection rounds was 30 items (5 two-digit number items; 5 three-digit number items; 4 four-digit number items; 4 five-digit number items; 4 six-digit number items; 4 seven-digit number items; and 4 eight-digit number items).

As described in the ECLS-K user manual, while multiple scores of the number reversed measure are available, the w score is the most appropriate for growth analysis. The w score is a special transformation of the Rasch ability scale and provides a common scale of equal intervals that represents both a child's ability and the task difficulty, which is particularly useful for the measurement of growth and can be considered a growth scale. Also, the w score is an equal-interval scale, suited for analyses such as correlations and regressions. Higher w scores indicate that a child provided more correct responses and generally indicate that a child was able to correctly respond to at least some longer number sequences. Typically, the w scale has a mean of 500 and standard deviation of 100. Furthermore, the publisher of the WJ III has set the mean to the average of performance for a child of 10 years, 0 months. This means that it would be expected that most children younger than 10 years, 0 months would obtain w scores lower than the mean of 500, and most older children would be expected to have scores above the mean of 500. Also, as a child develops with age, it would be expected that the child's w score would increase to reflect growth. For example, when a child's w-ability score increases from 420 to 440, this indicates growth, and this would be the same amount of growth in the measured ability as any other student who gained 20 w points elsewhere on the measurement scale.

4.2.3 Family Background Measures

(1) Family SES

The dataset contains a composite socioeconomic status (SES) measure for each child in the kindergarten year as well as in the 1st grade. For those with a missing value of SES in the kindergarten year, I used the value of SES in the 1st grade to approximate their SES in the kindergarten year. The composite variable for SES was created in a way that combined occupation prestige scores, income, and education.

4.2.4 School Characteristics Measures

(1) School Composition

School composition was measured by concentration of poverty (the percentage of students receiving free lunch), concentration of students of color (percentage of Hispanic students, percentage of black students, and percentage of non-white students), and concentration of English Language Learner (ELL) students (percentage of ELL students). All of these variables came from the school questionnaires that were reported by school administrators.

(2) School Funding Status

School funding status was measured by whether a school received Title I funding and whether a school received Title III funding, each based on administrator reports. Title I: "Improving the Academic Achievement of the Disadvantaged" is a program of the Elementary and Secondary Education Act (ESEA) of 1965, as reauthorized under the No Child Left Behind Act of 2001. The purpose of this program is to ensure that all children have a fair, equal, and significant opportunity to obtain a high-quality education and reach, at a minimum, proficiency on state academic achievement standards and state academic assessments. Title III: "Language Instruction for Limited English Proficient and Immigrant Students" is a program of the Elementary and Secondary Education Act (ESEA) of 1965, as reauthorized under the No Child Left Behind Act of 2001. One of the main purposes of this program is to help ensure that children who have limited proficiency in English, including immigrant children and youth, attain English proficiency, develop high levels of academic attainment in English, and meet the same state academic content and student academic achievement standards that all students are expected to meet (ECLS-K Spring 2013 School Administrator Questionnaire B).

(3) School Facility

School facility was measured by school's physical facilities, determined by a standardized score of 10 items asking the school administrator if the school facilities such as the cafeteria, computer lab, library, and classrooms met students' needs. More specifically, teachers were asked to report how adequate are each of the following 10 facilities for meeting the needs of children in the school: cafeteria, computer lab, library/media center, art room, gymnasium, music room, playground, classrooms, auditorium, and multi-purpose room. Each item was given 5 choices: do not have, never adequate, often not adequate, sometimes not adequate, always adequate. I constructed an overall school facility score combining measures from all the 10 items so that higher score indicates more sufficient school facilities.

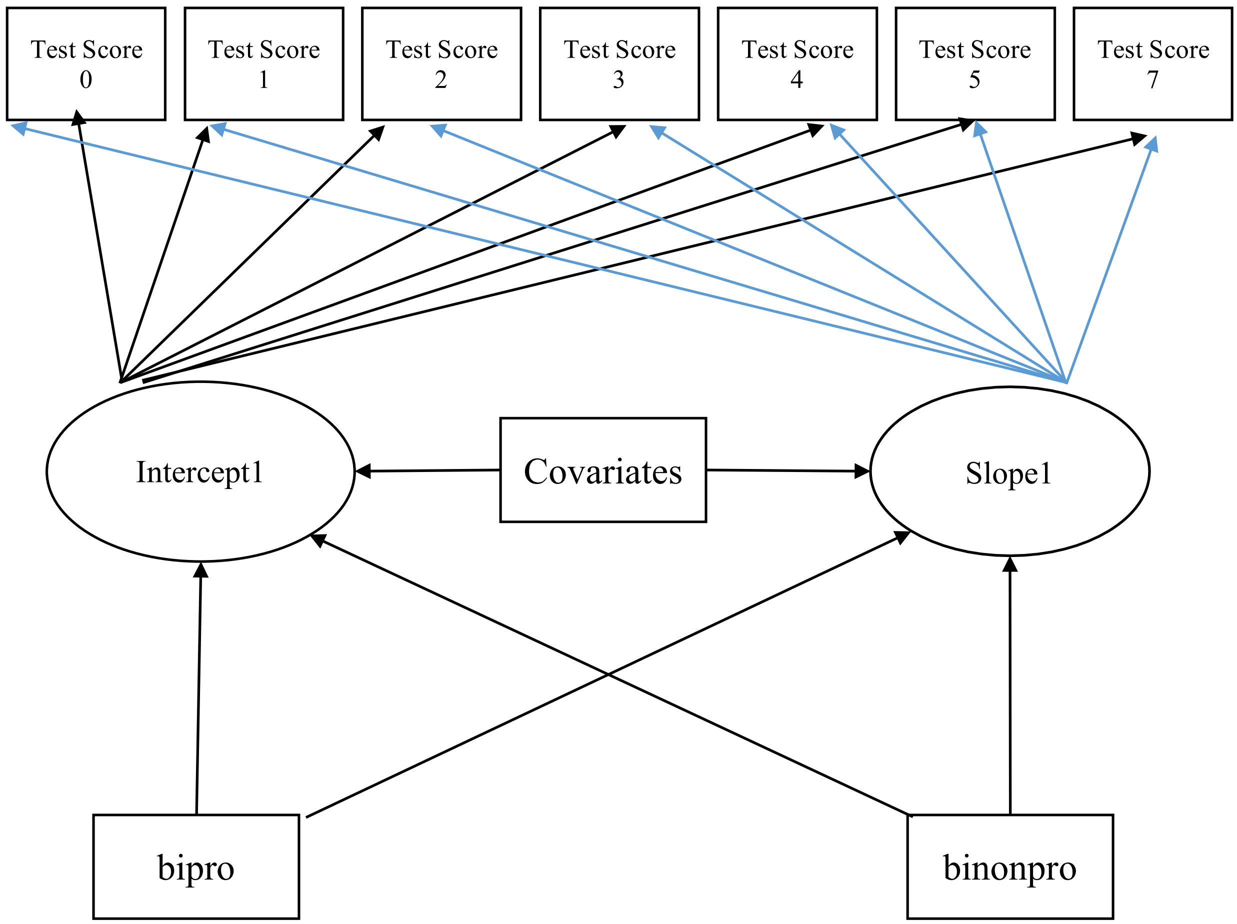
(4) School learning environment and climate

School learning environment and climate was measured by teacher-reported learning environment. A standardized score of 12 items included level of child misbehavior, academic standards, supportive staff, school-level staff cooperation, supportive parents and so on. Each of these items is given 5 options from strongly disagree to strongly agree. I constructed a composite school learning environment index by combining all the 12 items so that a higher score indicates a better learning environment.

4.3 Analytic Methods

4.3.1 Research Question 1: What are the differences in learning trajectories?

Figure 2
Growth model for IRT Scale Test Score from fall kindergarten to spring 3rd grade



Notes. The loadings and error terms are left out because it would be too cluttered with them included. The intercept has a loading of 1 for each wave of test scores; the slope has a loading of 0 for fall kindergarten, a loading of 1 for spring kindergarten, a loading of 2 for fall 1st grade, and so forth. The last wave, the spring of 3rd grade actually corresponds to a loading of 7 from the slope. Each wave of test scores also has an error term associated because there might be some error in the measurement at each wave.

To estimate the growth trajectories of students in different language status groups, I used Latent Growth Curve Models (LGCM) under the Structural Equation Model (SEM) framework. LGCM allows each student to have individual trajectories ("latent curves" or "growth curves") representing change of test scores over time from fall kindergarten to the spring of 3rd grade. SEM advances basic longitudinal analysis of data to include latent variable growth over time while modeling both individual and group changes using slopes and intercepts. In addition to mapping these trajectories, LGCM allow researchers to examine the determinants of these trajectories by including covariates. More specifically, LGCM models the growth of test scores by applying two latent variables in the model. The first is the random intercept (initial level), indicating students might start higher or lower on the test scores at fall kindergarten. The second possible random effect is the slope or rate of change, which represents the rate of growth in test scores from fall kindergarten to the spring of 3rd grade.

Another approach, which is also commonly used to estimate the growth but is not used in this study, is multilevel modeling, which employs the statistical techniques of general linear regression and specifies fixed and random effects. LGCM, on the other hand, considers change over time in terms of an underlying, latent, unobserved process. The two approaches are similar and in most cases they yield identical estimates. However, LGCM is more flexible than multilevel modeling in some regards and can explore questions that are not possible with multilevel modeling because it is employed within the SEM framework. For example, one can analyze and model mediational effects within a growth model using LGCM, which cannot be accomplished by a multilevel growth model. Therefore, in this dissertation, I employed the LGCM to model the growth trajectories of test scores.

To answer the first research question, I used a simple linear growth curve model where test scores are modelled to grow linearly from kindergarten entry to the end of 3rd grade. As shown in Figure 2, the variables of test scores from fall kindergarten to spring 3rd grade are observed variables. Per the description in the dataset section, ESCLS-K measured test scores for the 7 waves in total. From fall kindergarten to spring 2nd grade, the gaps between two measurements are around 6 months. Because ECLS-K did not measure test scores in fall 3rd grade, the gap between spring 2nd grade and spring 3rd grade is around 12 months. Thus, the intercept to each wave of test scores is always fixed at 1, and the loadings from the slope to test scores at each wave are 0, 1, 2, 3, 4, 5, 7; in this way, the intercept shows the projected initial level of test score trajectory at kindergarten entry, and the slope shows the growth rate per six months. The error terms of each wave of test scores are allowed to correlate; the error terms of intercept and slope are also allowed to correlate. To obtain the estimates of growth trajectories for students in different language status groups, I added two dummy indicators of language status: bipro and binonpro, in which monopro (monolingual English proficient group) is treated as the reference group. In this way, the constant for intercept and slope show the growth trajectory of the monolingual group, the coefficients of bipro and binonpro show the differences in growth trajectory between each of the two groups (bilingual EP students and bilingual LEP students) and the monolingual group.

To account for possible effects of family background and school characteristics in the learning growth trajectories, I added time-invariant covariates to the simple linear growth model. As shown in Figure 2, the covariates in the rectangle represent a list of variables indicating students' family background and school characteristics. When these time-invariant covariates are added to the model, the results will show the estimated intercepts and slopes after controlling for family background and school characteristics.

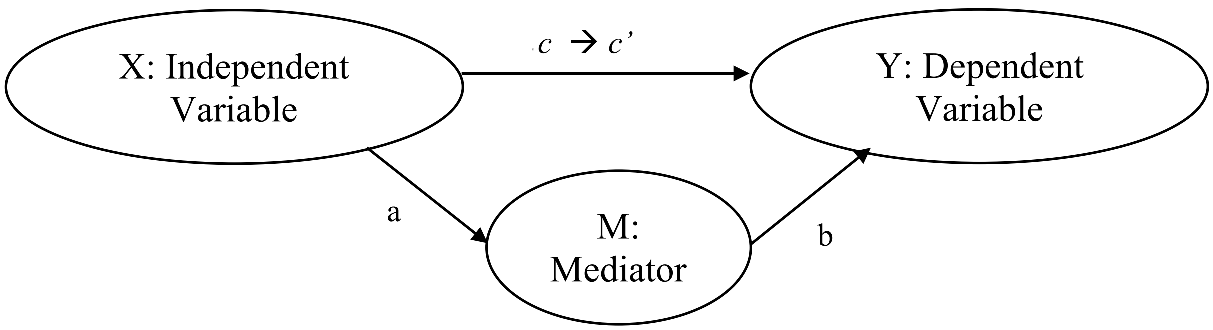
While a linear latent growth model can estimate the intercept and slope of each student's achievement trajectories in a neat and clear way, the actual growth curve could be non-linear. To test for the linearity assumption, I also estimated the model with quadratic terms of time and compared the nonlinear models and the linear models. In the end, I chose the simple linear models for two reasons. First, the quadratic terms in the nonlinear model did not have statistically significant coefficients. Second, the goodness-of-fit statistics showed that the model with quadratic term did not attain a better overall fit than the simple linear model.

To deal with missing data, I used the method (mlmv) specification in Stata. The option allows the model to use all available information and to obtain maximum likelihood estimates. More specifically, this method can retrieve as much information as possible from observations containing missing values and thus including all observations in the analysis sample in the regression.

4.3.2 Research Question 2: To what extent are the differences in growth trajectory mediated by working memory and cognitive flexibility?

Before presenting the mediation model in the latent growth curve framework, I first discuss the basic cross-sectional mediation model as a foundation. According to Baron and Kenny's (1986) seminal paper, mediation analysis is used to understand whether a factor can account for the connection between two variables. More specifically, in a mediational framework, there are three variables: independent variable, dependent variable, and mediator variable, all of which are shown in Figure 3. The total effect from X to Y (denoted by c) can be decomposed into the direct effect of X on Y (denoted by c') and the indirect effect through mediation (path a and b). The total effect thus can be expressed as $c = c' + a*b$. The size of the mediated effect $c - c'$ is equal to $a*b$. When c' is zero, the model has a complete mediation; when c' is not zero, the model has a partial mediation.

Figure 3 Baron and Kenny's (1986) basic mediation analysis framework



To describe the mediation analysis in the latent growth model framework, I present the model specification in the following mathematical formulas. First, the growth model can be expressed in the following latent variable equation (Bollen & Curran, 2006):

$$\boldsymbol{y_{it}} = \boldsymbol{\alpha_{iy}} + \boldsymbol{\beta_{iy}\lambda_t} + \boldsymbol{\varepsilon_{yit}} \quad (1)$$

Equation (1) represents the estimated trajectory of each student of the population during the time period under study. In this equation three subscripts are used: y identifies all test scores, whereas i and t identify individuals and time points, respectively. Thus, $\boldsymbol{y_{it}}$ is the value of the test score for individual i at time t; $\boldsymbol{\alpha_{iy}}$ is the random intercept for every individual i; $\boldsymbol{\beta_{iy}}$ represents the random slope for every individual; $\boldsymbol{\lambda_t}$ is a parameter used to represent time (in this study it is coded as 0, 1, 2, 3, 4, 5, 7); and $\boldsymbol{\varepsilon_{yit}}$ is the error term at each time point for each individual.

In this study I am interested in determining by which processes language status (bipro or binonpro)—the independent variable—predicts the intercept and growth rate in achievement trajectories. Following Baron and Kenny's (1986) procedure, a first step would be to test whether language status is in fact significantly related to the dependent variable, which is either the intercept or the slope of the test score growth. This has been accomplished by the first part of the analysis in model 1. As displayed in equation 1, two coefficients have been predicted by the independent variable, the intercept $\boldsymbol{\alpha_{iy}}$ and the slope $\boldsymbol{\beta_{iy}}$. Then the analysis will test how the independent variable (language status) is related to the intercept ($\boldsymbol{\alpha_{iy}}$) and the slope ($\boldsymbol{\beta_{iy}}$) of the dependent variable (test score) from kindergarten to the 3rd grade. For this purpose, the intercept and the slope of the dependent variable have to be regressed on the independent variable, as specified by the following slope equation:

$$\boldsymbol{\alpha_{iy} = \mu_{\alpha y} + \gamma_{\alpha y} x_i + \zeta_{y\alpha i}} \quad \text{(2a)}$$

$$\boldsymbol{\beta_{iy} = \mu_{\beta y} + \gamma_{\beta y} x_i + \zeta_{y\beta i}} \quad \text{(2b)}$$

In equation (2a), $\boldsymbol{\mu_{\alpha y}}$ is the intercept for the equation that predicts the random intercept from equation (1), which is also the estimated intercept for the reference group. $\boldsymbol{x_i}$ is the language status dummies predicting the slope, and $\boldsymbol{\gamma_{\alpha y}}$ is the regression coefficient of the independent variable, whereas $\boldsymbol{\zeta_{y\alpha i}}$ is the error term in the equation. In equation (2b), $\boldsymbol{\mu_{\beta y}}$ is the intercept for the equation that predicts the random slope, which is also the estimated slope for the reference group. $\boldsymbol{x_i}$ is the language status dummies predicting the slope, and $\boldsymbol{\gamma_{\beta y}}$ is the regression coefficient of the independent variable, whereas $\boldsymbol{\zeta_{y\beta i}}$ is the error term in the equation. $\boldsymbol{\gamma_{\alpha y}}$ and $\boldsymbol{\gamma_{\beta y}}$ are the coefficients representing the effect of language status on intercept and slope.

The next step to test mediation requires the introduction of the mediator variable—in this case, executive function. Because two different variables are measured in executive function, both cognitive flexibility and working memory are potential mediators. Since the working memory variable is measured at the same time points as the dependent variable, a growth curve comparable to the growth curve for test scores can be constructed for working memory. And the growth rate of working memory is then estimated to influence the growth rate of test scores. To proceed, the following trajectory equation for the working memory can be specified:

$$\boldsymbol{w_{it}} = \boldsymbol{\alpha_{iw}} + \boldsymbol{\beta_{iw}} \boldsymbol{\lambda_t} + \boldsymbol{\varepsilon_{wit}} \qquad (3)$$

This growth curve equation represents the expected trajectory of each student of the population during the time period under study for the mediator variable. The subscripts have same meanings as those in equation (1): $\boldsymbol{w_{it}}$ is the value of working memory for individual i at time t, whereas $\boldsymbol{\alpha_{iw}}$ and $\boldsymbol{\beta_{iw}}$ represent the random intercept and slope, respectively, for every individual. $\boldsymbol{\lambda_t}$ is a parameter used to represent time (in this study it is coded as 0, 1, 2, 3, 4, 5, 7). The error term at each time point for each individual is represented by $\boldsymbol{\varepsilon_{wit}}$.

In this case, two types of information about the mediation variable can be used in the mediation analyses: the random intercepts (students' initial status of executive function) and the random slopes (the growth of executive function over time). Because ECLS-K administered both cognitive flexibility and working memory to measure executive function, in the following analysis, I will consider both variables as potential mediators. However, because ECLS-K used physical version of the Dimensional Change Card Sort (DCCS) (Zelazo 2006; Zelazo et al. 2013) for kindergarten and used a computerized version of the DCCS starting 2nd grade, the way the construct of cognitive flexibility is assessed and scored differently across time. Thus the study is not able to obtain the estimates of the growth of cognitive flexibility and hence not able to test the mediation of the growth in cognitive flexibility. In fact, when considering how the growth rate of executive function mediates the growth rate in test scores, the mediation analysis will only include the growth of working memory. However, the model will include the part which represents how the kindergarten entry cognitive flexibility mediates the initial level of achievement growth trajectory. The model can mathematically be expressed by the following equations:

$$\boldsymbol{\alpha_{iw}} = \boldsymbol{\mu_{\alpha w}} + \boldsymbol{\gamma_{\alpha w} x_i} + \boldsymbol{\zeta_{\alpha wi}} \tag{4}$$

$$\boldsymbol{\beta_{iw}} = \boldsymbol{\mu_{\beta w}} + \boldsymbol{\gamma_{\beta w} x_i} + \boldsymbol{\zeta_{\beta wi}} \tag{5}$$

In equation (4), $\boldsymbol{\alpha_{iw}}$ is the intercept of working memory, which is regressed on the language status dummies. Other parameters have similar meanings to that of previous models. $\boldsymbol{\gamma_{\alpha w}}$ is the parameter of interest from this equation, which represents the direct effect from independent variable (language status) to mediator (the initial level of working memory). Similarly, in equation (5), the growth rate/ slope of working memory is regressed on the language status dummies, and the resulting coefficient $\boldsymbol{\gamma_{\beta w}}$ will show the direct effect from independent variable (language status) to mediator (the slope of working memory).

Additionally, the fall kindergarten cognitive flexibility will be regressed on the independent variable to get a direct effect from the language status to the mediator (the initial level of cognitive flexibility). This model is shown in the following equation (6):

$$\boldsymbol{z_i} = \boldsymbol{\alpha_{iz}} + \boldsymbol{\beta_{iz} x_i} + \boldsymbol{\varepsilon_{zi}} \tag{6}$$

Where $\boldsymbol{z_i}$ represents the cognitive flexibility measured at fall kindergarten for student i, and $\boldsymbol{x_i}$ is the language status of student i. $\boldsymbol{\varepsilon_{zi}}$ is the error term and $\boldsymbol{\alpha_{iz}}$ represents the initial level of cognitive flexibility for the reference growth (the monolingual proficient students). $\boldsymbol{\beta_{iz}}$ will show the direct effect of independent variable (language status) on the mediator (the initial level of cognitive flexibility).

Finally, the dependent variables (the intercept and slope of test score growth) are regressed on both the independent variables (language status dummies) and the mediators (initial level of working memory, slope of working memory, and the initial level of cognitive flexibility). This leads to the following models:

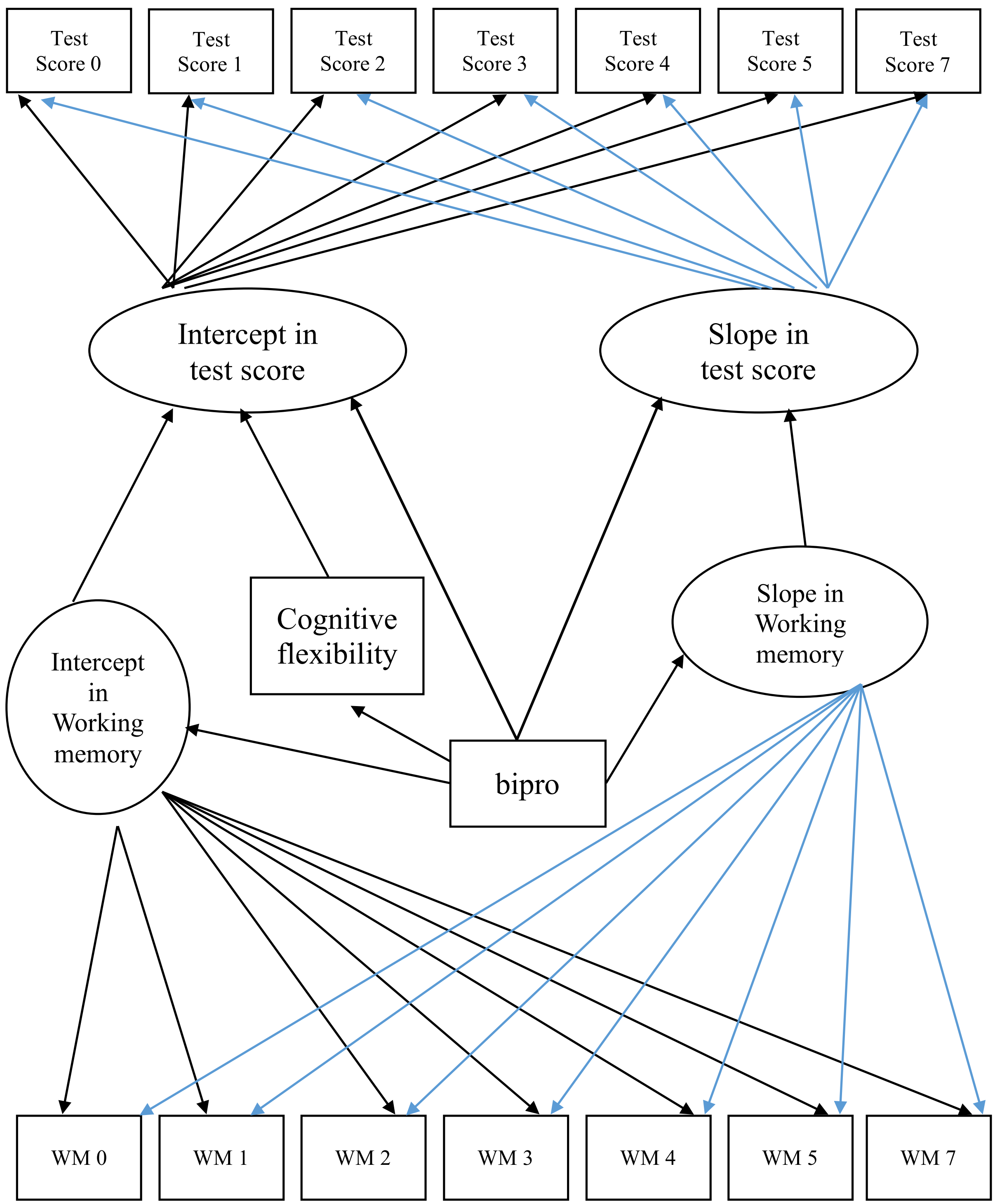
$$\boldsymbol{\alpha_{iy}} = \boldsymbol{\mu_{\alpha y}} + \boldsymbol{\delta_{\alpha y}}\alpha_{iw} + \theta_{\alpha y}\beta_{iz} + \gamma'_{\alpha y}x_i + \zeta_{y\alpha i} \quad (7)$$

$$\beta_{iy} = \mu_{\beta y} + \delta_{\beta y}\beta_{iw} + \gamma'_{\beta y}x_i + \zeta_{y\beta i} \quad (8)$$

In equation (7), the intercept of dependent variable (test scores) α_{iy} is regressed on the language status dummies indicated by x_i and the two mediators (the intercept of working memory α_{iw} and the initial level of cognitive flexibility β_{iz}). The resulting coefficient $\delta_{\alpha y}$ will show the direct effect of working memory intercept on test score growth intercept; coefficient $\theta_{\alpha y}$ will show the direct effect of the initial level of cognitive flexibility on test score growth intercept. $\gamma'_{\alpha y}$ will show the direct effect of language status on the test score intercept, which is also the remaining effect that is not mediated by executive functions. Similarly, in equation (8), the slope of dependent variable (test score) β_{iy} is regressed on the language status dummies indicated by x_i and the mediator (the slope of working memory growth β_{iw}). The resulting coefficient $\delta_{\beta y}$ will show the direct effect of slope in working memory on the slope of test score growth. $\gamma'_{\beta y}$ will show the direct effect of language status on the test score slope, which is also the remaining effect that is not mediated by the growth of working memory.

Taken together, the series of mediational analysis can be combined in a SEM latent growth mediation model depicted in figure 3. As shown in figure 3, independent variable can influence the initial level and the growth of working memory, as well as the initial level of cognitive flexibility. Both the working memory and cognitive flexibility at kindergarten entry will contribute to the differences in the intercept of test score growth by language status. The differences in the growth rate of working memory will contribute to the differences in the slope of test score growth by language status. The effect of language status on the initial level of test scores is thus decomposed to be direct effect from the language status itself and the indirect effect from the mediation of the initial level of working memory and cognitive flexibility. The effect of language status on slope in test score growth is thus decomposed to be direct effect from the language status itself and the indirect effect from the mediation of the slope of working memory growth from kindergarten to 3rd grade. To show the directions and relationships clearly, I only included bipro language status in this figure, but the mediational model for binonpro language status is the same. Additionally, I skipped the family and school covariates in the figure, but they are included in all the steps of the mediation analysis.

Figure 4
A multiple mediation model for bilingual proficient students



Notes. The elliptical circles represent the latent variables estimated in the model, and the rectangular shapes represent the observed variables. The slope and intercept of working memory are estimated from a latent growth curve model of working memory growth. The cognitive flexibility is the DCCS score measured at fall kindergarten. The model includes both bipro and binonpro dummies, the binonpro variable is left out because it would be too cluttered with it in.

CHAPTER V. Results

Part I Differences in learning trajectories among students of different initial language status

5.1 Descriptive statistics

Table 1a presents the descriptive statistics of the test scores and executive function measures from the analysis sample. As the table shows, compared to monolingual proficient students, both bilingual EP students and bilingual LEP students have lower test scores from kindergarten entry to the end of 3rd grade. For executive functions, while the bilingual students started lower than monolingual students in kindergarten, they were able to attain a level of scores in both cognitive flexibility and working memory that are comparable to that of monolingual students. Compared to bilingual EP students, the test scores and executive function measures for bilingual LEP students are even lower.

Table 1a. Mean and standard deviations of test scores and executive functions

	(1) Overall Mean(sd)	(2) Monolingual Mean(sd)	(3) Bilingual-EP Mean(sd)	(4) Bilingual-LEP Mean(sd)
Reading IRT scale score				
Fall kindergarten	47.89	50.53	48.80	41.42
	(9.89)	(10.20)	(9.30)	(6.40)
Spring kindergarten	61.47	65.03	62.47	52.71
	(12.68)	(12.74)	(11.22)	(9.93)
Fall 1st grade	68.99	72.13	69.65	62.51
	(14.26)	(15.26)	(12.69)	(11.83)
Spring 1st grade	83.56	87.89	84.72	73.78
	(16.20)	(16.03)	(14.49)	(14.31)
Fall 2nd grade	89.02	93.20	90.15	81.15
	(14.63)	(14.34)	(13.61)	(12.97)
Spring 2nd grade	97.78	101.45	99.00	89.51
	(14.07)	(13.36)	(12.63)	(13.62)
Spring 3rd grade	106.09	109.44	107.12	98.89
	(12.74)	(12.14)	(11.15)	(12.67)
Math IRT scale score				

Fall kindergarten	29.18	32.18	29.97	22.25
	(10.41)	(10.44)	(9.53)	(7.77)
Spring kindergarten	43.53	46.34	44.06	36.89
	(11.78)	(11.64)	(10.60)	(10.91)
Fall 1st grade	51.14	54.20	51.73	45.31
	(13.39)	(14.01)	(11.94)	(11.89)
Spring 1st grade	64.36	67.89	65.18	56.53
	(15.16)	(15.31)	(13.67)	(13.76)
Fall 2nd grade	69.43	73.11	70.25	62.71
	(15.34)	(15.03)	(13.62)	(15.44)
Spring 2nd grade	81.38	84.62	82.79	73.68
	(15.11)	(14.50)	(13.32)	(15.56)
Spring 3rd grade	92.92	96.02	93.29	86.94
	(14.03)	(13.67)	(12.79)	(14.21)
Science IRT scale score				
Spring kindergarten	27.53	30.50	26.58	21.60
	(6.45)	(6.16)	(5.38)	(3.38)
Fall 1st grade	29.85	33.27	29.33	24.22
	(7.46)	(7.54)	(6.22)	(4.51)
Spring 1st grade	34.80	38.72	34.48	27.49
	(9.23)	(9.12)	(7.72)	(6.18)
Fall 2nd grade	37.35	41.65	37.95	29.89
	(9.98)	(8.69)	(8.27)	(9.30)
Spring 2nd grade	43.23	47.08	43.85	35.36
	(10.40)	(9.14)	(8.99)	(9.86)
Spring 3rd grade	50.87	53.91	51.57	44.61
	(10.06)	(9.30)	(9.07)	(9.69)
Cognitive flexibility				
Fall kindergarten	13.51	14.16	13.79	11.89
	(3.68)	(3.24)	(3.38)	(4.32)
Spring kindergarten	14.79	15.20	14.91	13.80
	(2.86)	(2.60)	(2.64)	(3.39)
Fall 1st grade	15.45	15.83	15.49	14.77
	(2.38)	(2.11)	(2.34)	(2.69)
Spring 1st grade	15.76	16.05	15.87	15.08
	(2.35)	(2.25)	(2.05)	(2.74)
Fall 2nd grade	6.09	6.37	6.26	5.46
	(1.58)	(1.44)	(1.45)	(1.76)
Spring 2nd grade	6.57	6.75	6.70	6.09
	(1.38)	(1.26)	(1.26)	(1.58)

Spring 3rd grade	7.09	7.22	7.21	6.71
	(1.11)	(1.02)	(0.93)	(1.35)
Working memory				
Fall kindergarten	422.83	430.22	423.64	407.21
	(27.89)	(28.96)	(27.40)	(18.34)
Spring kindergarten	440.59	447.18	441.09	426.02
	(30.84)	(29.83)	(30.41)	(28.53)
Fall 1st grade	450.64	455.05	453.15	440.38
	(29.32)	(28.48)	(27.87)	(29.86)
Spring 1st grade	463.10	468.35	464.50	451.23
	(27.38)	(25.17)	(25.86)	(29.67)
Fall 2nd grade	469.41	473.67	471.03	460.92
	(24.63)	(22.59)	(22.50)	(27.69)
Spring 2nd grade	477.64	480.75	479.51	469.65
	(22.94)	(21.49)	(21.35)	(25.41)
Spring 3rd grade	486.80	488.94	488.17	481.33
	(20.95)	(20.28)	(19.50)	(22.77)
N	4091	1959	1191	941

Notes. The standard deviations are in the brackets. All cognitive measures except science are assessed for a total of 7 waves starting from fall kindergarten to spring 3rd grade. Science assessment was first administered in spring kindergarten. All cognitive measures except cognitive flexibility share the same scale from kindergarten to 3rd grade. For cognitive flexibility, the scale and assessment are different before and after 2nd grade.

Table 1b presents the differences in family SES and school characteristics by the different language status. As shown in the table, compared to monolingual Hispanic students, bilingual Hispanic students on average come from families with a lower SES. They are also more likely to attend a public and poorer school, to have a less desirable school learning environment, and to enroll in a school with a higher percentage of minority students, ELL students, and free lunch eligible students. More specifically, bilingual LEP students have a family background and school characteristics that are even more disadvantaged than that of bilingual EP students. The table also includes the descriptive stats of preLAS score indicating students' English proficiency at kindergarten entry. Specifically, both monolingual and bilingual-proficient students have an average of preLAS score above the overall mean; the bilingual non-proficient students, however, have an average preLAS score of 9.72, which is much less than the overall mean of preLAS score.

Table 1b. Descriptive statistics of English proficiency, family background, and school characteristics from kindergarten to 3rd grade

	(1) Overall mean/sd	(2) Monolingual mean/sd	(3) Bilingual-Pro mean/sd	(4) Bilingual-Nonpro mean/sd
PreLAS score at kindergarten entry	16.69	19.18	18.10	9.72
	(4.62)	(1.10)	(1.42)	(4.87)
Socioeconomic status	-0.54	-0.21	-0.75	-0.95
	(0.69)	(0.70)	(0.56)	(0.45)
Whether the child born in the US	0.96	0.99	0.96	0.92
Month staying in the US	65.94	66.85	66.42	63.76
	(7.30)	(4.52)	(7.06)	(10.54)
Whether attended a public school	0.93	0.89	0.96	0.99
Average school facility	3.80	3.81	3.79	3.80
	(0.68)	(0.70)	(0.69)	(0.63)
Teacher reported school environment	0.00	0.05	-0.04	-0.04
	(0.41)	(0.41)	(0.42)	(0.37)
Average percent of minority	72.04	63.26	76.83	84.19
	(27.70)	(29.67)	(24.81)	(19.74)
Average percent of free lunch eligible students	68.00	58.48	73.07	81.34
	(27.58)	(29.82)	(23.82)	(18.46)
Average percent of ELL students	29.45	20.12	33.65	42.78
	(22.84)	(19.27)	(22.08)	(22.15)
Whether received title I	0.85	0.78	0.87	0.93
Whether received title III	0.60	0.55	0.64	0.67
N	4091	1959	1191	941

Notes. Family SES is measured in more than one waves of data collection. I used the family SES measure at kindergarten entry as the basis, and then use the family SES measured at fall 1st grade to approximate that basis if the fall kindergarten measurement of SES is missing. I also looked at whether a student in born in the US, how long has the student stayed in the US, and whether a student attend a public school to further capture students' family background. But these variables are not significantly related to the outcome estimates given SES is included in the regression models, so the descriptive stats of these variables are presented here in this table, but they are not included the later regression models. For all of the school characteristics measures, I averaged the measures across all measures available in different waves to approximate the average quality of school environment.

5.2 Differences in learning trajectories by language status

Table 2. Differences in learning trajectories

	Reading		Math		Science	
Whether include controls	No	Yes	No	Yes	No	Yes
Intercept						
bipro	-2.107***	0.0597	-2.242***	0.0320	-4.086***	-2.434***
	(0.397)	(0.414)	(0.389)	(0.407)	(0.205)	(0.211)
binonpro	-11.17***	-8.109***	-9.966***	-6.791***	-9.717***	-7.369***
	(0.431)	(0.479)	(0.420)	(0.468)	(0.230)	(0.249)
constant	54.85***	55.44***	36.38***	36.62***	30.44***	33.58***
	(0.304)	(1.275)	(0.264)	(1.245)	(0.127)	(0.647)
Slope						
bipro	-0.0157	0.136	0.0570	0.174*	0.276***	0.385***
	(0.0748)	(0.0814)	(0.0665)	(0.0725)	(0.0505)	(0.0546)
binonpro	-0.0614	0.155	-0.00742	0.145	-0.0738	0.0612
	(0.0806)	(0.0933)	(0.0708)	(0.0824)	(0.0558)	(0.0636)
constant	8.770***	8.873***	9.001***	8.685***	3.969***	3.495***
	(0.0748)	(0.259)	(0.0525)	(0.229)	(0.0320)	(0.172)

Notes. There are two columns of coefficients for each subject. the left column does not control for family and school characteristics, representing the simple, unconditional growth model of test scores. The right column controls for family and school characteristics, representing the conditional growth model where family and school characteristics are estimated to explain the initial level and growth rate of test scores. The sample size is 4092 with 1959 monopro, 1191 bipro, and 941 binonpro. The missing values are handled by the maximum likelihood with missing values (mlmv) options in Stata SEM command. The reference group is monolingual English proficient students.

Table 2 presents the differences in learning trajectories among the three different groups of students. For the sake of simplicity, this table only shows the coefficients for intercept and slope estimates. A table presenting the coefficients for all variables including covariates is included in the appendix. As shown in Table 2, the constants for slope and intercept in each model show the growth rate and initial level of test score growth trajectory for monolingual English proficient students. For example, for the reading subject, monolingual students have a predicted average test score of 54.85 points at the initial level (kindergarten entry) and their test scores increase by around 8.77 points for every half year. The coefficients for bipro and binonpro show the differences between each of the two groups and the reference group (monolingual) students in intercepts and slopes. For example, the first column in the first row shows that compared to monolingual students, bilingual EP students' growth rate in reading test score is about 0.016 points lower, and the difference is not significant. In other words, bilingual EP students demonstrated a growth rate that is about the same as that for monolingual students. Bilingual LEP students also have a growth rate in reading that is not significantly different from that of monolingual proficient students.

After controlling for family and school covariates, bilingual EP students have similar initial level of reading score to that of the monolingual students; bilingual LEP students, however, still have an initial level of reading score that is around 8 points lower than monolingual students. This suggests a quite large gap in reading score at kindergarten entry between bilingual LEP students and monolingual students; even family background and school characteristics are not able to explain that gap away. When looking at the growth rate for reading scores after controlling for family and school characteristics, both bilingual EP students and bilingual LEP students have a higher growth rate than the monolingual group, indeed, the bilingual LEP students have a growth rate that is the highest among the three groups (0.155 points higher than monolingual students), however, these differences in growth rate are not statistically significant.

As for math scores, the intercepts show very similar patterns to that of reading scores. Both bilingual groups have lower initial levels of math scores than monolingual students. After controlling for family and school characteristics, while the bilingual EP group is estimated to have a similar level of initial math score to that of the monolingual students, bilingual LEP students have an average of initial math score that is about 6.8 points lower than monolingual students. This shows that at kindergarten entry, the bilingual LEP Hispanic students are the most disadvantaged group in math achievement as well.

As for the growth rate in math, the third column of slope coefficients in Table 2 shows that both bilingual groups have similar growth to that of monolingual students in their math achievement trajectories. After controlling for family background and school characteristics, both bilingual EP students and bilingual LEP students demonstrated a growth rate that is higher than that for monolingual students. Specifically, the growth rate for bilingual EP students is around 0.17 points higher than that for monolingual students; the growth rate for bilingual LEP students is around 0.15 points higher than for monolingual students. This suggests that bilingual students might be able to obtain a higher growth rate even with a lower initial math score given that family and school factors are held constant.

As for science scores, the patterns show unusual aspects that are not observed in reading and math scores. First, both groups of bilingual students show a much lower initial level of science scores than the monolingual group; even after controlling for family and school covariates. Second, the bilingual EP group shows a much higher growth rate (around 0.28 points per half year) than monolingual students, while the bilingual LEP group has a growth rate that is not significantly different from monolingual students. After controlling for family and school characteristics, the differences in science growth rate do not change much: bilingual EP students still have a higher growth rate (around 0.39 points higher than monolingual students); bilingual LEP students demonstrate a medium advantage (around 0.06 points higher than monolingual students), but the advantage is not statistically significant.

In conclusion, compared to monolingual students, both bilingual EP students and bilingual LEP students have lower initial test scores in all the three subjects. While the initial gap in test scores between bilingual EP students and monolingual students are largely explained by family and school characteristics, the test score gaps between bilingual LEP students and monolingual students are still large even after controlling for family and school covariates. In terms of learning growth rate, all students show positive growth in test scores in all three subjects. While bilingual EP students have a higher growth rate than monolingual students in all three subjects, bilingual LEP students only have non-significantly higher growth rate than monolingual students in reading and math. Bilingual LEP students do not have a higher growth rate in science even after controlling for family and school characteristics.

It is reassuring to see that both of the bilingual groups show higher or at least equal growth rate than monolingual students. However, given that the initial gaps between language minority students and monolingual students are so large, it would take them far too long to actually close the achievement gaps naturally because their test score growth rate is only a little larger than that of monolingual students. Thus, it is important to understand the extent to which we can further decompose the initial gaps in test scores and the growth rate differences between students of different language status so as to inform possible educational interventions. Additionally, it is also interesting to see that the growth rate advantage seems to be more obvious in bilingual EP students than bilingual LEP students in both math and science. This result motivates us to think and speculate why. Is it possible that the difference will show some pattern after the effects are decomposed to direct effects and indirect effects through cognitive mediation? The results from the mediational LGM in the Part II will give answers to such questions.

Part II Mediation by executive function

5.3 To what extent are the differences in academic trajectories mediated by the development of executive function?

Table 3a. Latent growth curve mediation model for reading

	Independent -> Mediator	Mediator -> Dependent	Indirect effect	Direct effect	Total effect
Slope of WM					
bipro	0.329**	0.475***	0.156**	-0.036	0.120
	(0.157)	(0.057)	(0.077)	(0.098)	(0.075)
binonpro	1.461***	0.475***	0.695***	-0.560***	0.134
	(0.178)	(0.057)	(0.118)	(0.137)	(0.085)
Intercept of WM					
bipro	-0.729	0.481***	-0.371	0.545	0.174
	(0.880)	(0.012)	(0.424)	(0.452)	(0.445)
binonpro	-15.537***	0.481***	-7.848***	-0.208	-8.056***
	(1.007)	(0.012)	(0.519)	(0.547)	(0.512)
Initial level of CF					
bipro	-0.102	0.201***	-0.371	0.545	0.174
	(0.156)	(0.041)	(0.424)	(0.452)	(0.445)
binonpro	-1.901***	0.201***	-7.848***	-0.208	-8.056***
	(0.176)	(0.041)	(0.519)	(0.547)	(0.512)

Note. The intercept of working memory growth and the initial level of cognitive flexibility are set to mediate the relationship between language status and the intercept of reading growth; the slope of working memory growth is set to mediate the relationship between language status and the slope of reading growth. Family SES and school characteristics are included in the model as covariates.

As shown in Table 3a, both bilingual EP and bilingual LEP students have a faster growth rate in reading than their monolingual peers, and this effect can be largely decomposed to the indirect effect operating though the mediation of the growth rate in working memory. Specifically, bilingual EP students have a growth rate in working memory that is around 0.33

points higher than monolingual students; bilingual LEP students have a growth rate that is much higher (1.46 points higher) than monolingual students. Because the effect of growth in working memory is translated to the growth in reading scores with an effect size of 0.475 units, the faster working memory growth for language minority students then translates into faster growth rate in reading achievement. Specifically, the resulting indirect effect of being bilingual EP on reading growth rate is 0.156 points; the resulting indirect effect of being bilingual LEP on reading growth rate is 0.695 points. Despite both groups having large positive indirect effects, the direct effects for both bilingual EP and LEP students are negative, so the resulting total effects are moderately positive for both groups.

Table 3a also shows the mediational role of the intercept of working memory trajectory and the initial level of cognitive flexibility on the relationship between language status and the intercept of reading growth. At the kindergarten entry, both bilingual EP and bilingual LEP students have lower initial level of working memory than their monolingual peers. Specifically, bilingual EP students' initial working memory is only slightly lower than monolingual students; bilingual LEP students have an initial working memory that is around 15.54 points lower than monolingual students. Because the initial level of working memory is translated to the initial level of reading test score with an effect size of around 0.48 units, the initial gaps in working memory resulted in initial gaps in reading at kindergarten entry. The initial level of cognitive flexibility is also lower for language minority groups. More specifically, bilingual EP students have a cognitive flexibility that is around 0.1 points lower than monolingual students. This gap is very small and not significant. Bilingual LEP students, however, have a cognitive flexibility that is around 2 points lower than monolingual students. Since cognitive flexibility has a direct effect of 0.2 points on the initial level of reading score, the lower cognitive flexibility then translates to the lower initial level of test score for language minority students through mediation. Considering both mediators, bilingual EP students have an indirect effect of -0.37 points and bilingual LEP students have a large indirect effect of -7.85 points. These indirect effects, complemented by the direct effects of language status on the initial level of reading achievement, resulted in a large gap in reading between bilingual LEP students and monolingual students. Indeed, bilingual LEP students have an average of reading test score that is around 8 points lower than that of monolingual students at kindergarten entry.

In sum, executive function is an important mediator in both the initial level and the slope of reading achievement trajectory. Because bilingual LEP students have a much lower initial level of working memory and cognitive flexibility starting at kindergarten than monolingual students, their reading test scores are also much lower. While bilingual LEP students are able to gain a faster growth rate in working memory than their monolingual peers over the first four years of school, which then translates into large positive reading growth rate, bilingual LEP students have a much lower growth rate in reading resulting from other channels or the language status itself (shown as direct effect in column 4 row 2). Thus the resulting total effect of bilingual LEP language status on reading growth is only moderately positive. Given a growth rate of 0.134 points per half year higher than monolingual students, it would take bilingual LEP students almost 30 years to fully close the initial reading test score gap of 8.056 points. Thus, it is important for future educational interventions to focus on closing the reading test score gap between bilingual LEP students and monolingual students, either by narrowing the initial gap at or before kindergarten entry, or by improving the growth rate of reading test scores over the first several years of schooling. Targeting either before kindergarten or after kindergarten, the executive function skills in working memory and cognitive flexibility seem to be important to focus on because of their significant role in mediating the relationship between language status and reading growth trajectory.

Table 3b. Latent growth curve mediation model for math

	Independent -> Mediator	Mediator -> Dependent	Indirect effect	Direct effect	Total effect
Slope of WM					
bipro	0.345**	0.550***	0.190**	-0.039	0.151**
	(0.159)	(0.052)	(0.089)	(0.101)	(0.071)
binonpro	1.448***	0.550***	0.796***	-0.653***	0.144
	(0.181)	(0.052)	(0.124)	(0.135)	(0.081)
Intercept of WM					
bipro	-0.829	0.532***	-0.478	0.65	0.171
	(0.870)	(0.011)	(0.466)	(0.416)	(0.409)
binonpro	-15.623***	0.532***	-8.935***	2.089***	-6.847***
	(0.996)	(0.011)	(0.561)	(0.505)	(0.470)
Initial level of CF					
bipro	-0.113	0.331***	-0.478	0.65	0.171
	(0.156)	(0.036)	(0.466)	(0.416)	(0.409)
binonpro	-1.892***	0.331***	-8.935***	2.089***	-6.847***
	(0.176)	(0.036)	(0.561)	(0.505)	(0.470)

Note. The intercept of working memory growth and the initial level of cognitive flexibility are set to mediate the relationship between language status and the intercept of math growth; the slope of working memory growth is set to mediate the relationship between language status and the slope of math growth. Family SES and school characteristics are included in the model as covariates.

As shown in Table 3b, bilingual EP students have a faster (around 0.35 points higher) growth rate in working memory than monolingual students; bilingual LEP students have a much higher growth rate than both bilingual EP and monolingual students. Indeed, bilingual LEP students have a growth rate in working memory that is about 1.5 points per half year faster than monolingual students. Because the growth rate in working memory is translated to the growth rate in math achievement with an effect size of 0.55 units, both bilingual EP and bilingual LEP students have higher growth rates in math achievement mediated by working memory growth (as shown in the indirect effects). Specifically, the indirect effect of bilingual EP on math growth slope is 0.19 units and the indirect effect of bilingual LEP on math growth rate is around 0.8 units. Despite the positive indirect effects through the growth rate in working memory, the resulting total effects are only moderately positive because the direct effects of bilingual EP and bilingual LEP on math growth slope are negative.

Table 3b also shows the mediational role of the initial level of working memory and cognitive flexibility on the relationship between language status and the initial level of math trajectory. Both groups of bilingual students have a lower working memory than monolingual students starting from kindergarten. Bilingual LEP students have a particularly low initial level of working memory that is around 15.6 points lower than that of monolingual students. Because the initial level of working memory is translated to the initial level of math test score with an effect size of around 0.5 units, the resulting indirect effect of bilingual LEP on the intercept of math trajectory is particularly large and negative. Similar patterns exist for cognitive flexibility. While bilingual EP students have an initial level of cognitive flexibility that is comparable to that of monolingual students, bilingual LEP students' cognitive flexibility at kindergarten entry is around 1.9 points lower than that of monolingual students. Also, the cognitive flexibility has a direct effect of 0.33 units on the initial level of math achievement. Considering the indirect effect through both working memory and cognitive flexibility, the indirect effect for bilingual EP is around -0.5 points and the indirect effect of bilingual LEP is around -8.9 points. In the end, the indirect effects complemented by the direct effects results in a large and negative effect of bilingual LEP on the initial level of math achievement, which is around 6.8 points lower than that of monolingual students.

The math trajectory pattern is similar to what is observed for the reading trajectory. Both bilingual EP and bilingual LEP students have much lower math test scores than monolingual students beginning from kindergarten entry, and this is largely mediated by their lower level of working memory and cognitive flexibility. While both groups are able to attain a faster growth rate in working memory trajectory that is mediating the growth in math achievement, because the direct effects from being bilingual EP are LEP are negative, the resulting total effects are only moderately positive. Bilingual LEP students are particularly disadvantaged in that they not only have a large gap in math scores compared to their monolingual peers, their growth rate is not high enough for them to close the gap in elementary years. In fact, given bilingual LEP students increase their math score by around 0.14 points per half year, it would take them around 25 years to finally close the initial gap of 6.8 points. Thus it is important for future educational interventions to reduce the achievement gaps between bilingual LEP students and monolingual students by targeting executive function, since the results show strong evidence that the development of executive function is mediating the relationship between language status and math achievement trajectory.

Table 3c. Latent growth curve mediation model for science

	Independent -> Mediator	Mediator -> Dependent	Indirect effect	Direct effect	Total effect
Slope of WM					
bipro	0.196	0.845***	0.166	0.222	0.388***
	(0.155)	(0.046)	(0.132)	(0.135)	(0.054)
binonpro	1.317***	0.845***	1.113***	-1.035***	0.078
	(0.176)	(0.046)	(0.160)	(0.163)	(0.063)
Intercept of WM					
bipro	-0.444	0.076***	-0.066	-2.460***	-2.526***
	(0.915)	(0.007)	(0.080)	(0.219)	(0.221)
binonpro	-15.849***	0.076***	-1.691***	-6.327***	-8.018***
	(1.047)	(0.007)	(0.144)	(0.276)	(0.258)
Initial level of CF					
bipro	-0.125	0.257***	-0.066	-2.460***	-2.526***
	(0.156)	(0.027)	(0.080)	(0.219)	(0.221)
binonpro	-1.907***	0.257***	-1.691***	-6.327***	-8.018***
	(0.176)	(0.027)	(0.144)	(0.276)	(0.258)

Note. The intercept of working memory growth and the initial level of cognitive flexibility are set to mediate the relationship between language status and the intercept of science growth; the slope of working memory growth is set to mediate the relationship between language status and the slope of science growth. Family SES and school characteristics are included in the model as covariates.

Table 3c shows the results from the mediational model for science achievement growth. As showed from the results for reading and math, both bilingual EP and bilingual LEP students show faster growth rates in working memory than their monolingual peers. Specifically, bilingual LEP students' growth rates in working memory are 1.3 points higher than that of monolingual students. The faster growth rate in working memory then translates to faster growth in science achievement because the slope of working memory growth has a direct effect of around 0.85 units on the slope of science achievement growth. The indirect effect of bilingual EP students is 0.17 points, which is relatively small and not significant. The indirect effect of bilingual LEP students is as large as 1.11 points. When these indirect effects are complemented by direct effects, the total effects are 0.39 points for bilingual EP students and 0.08 points for bilingual LEP students. While bilingual LEP students attain a large positive effect on science growth mediated by working memory growth, the direct effect (resulting from being bilingual LEP itself or other channels) is significantly negative (around -1.04 points), thus the resulting total effect for LEP students is only moderate.

Table 3c also shows mediation for the intercept of science trajectory. Both bilingual EP and bilingual LEP students are lower than that of their monolingual peers. Bilingual LEP students have an initial level of working memory that is around 16 points lower than monolingual students. Bilingual LEP students' cognitive flexibility is around 2 points lower than monolingual students. Because the initial level of working memory has an effect of around 0.08 units on the initial level of science achievement, and the initial level of cognitive flexibility has an effect of around 0.3 units on science achievement, the gaps in working memory and cognitive flexibility then translate into the gaps in the initial level of science scores. Specifically, the total indirect effect of the two mediators is around -0.07 units for bilingual EP students and around -1.70 points for bilingual LEP students. At the same time, the direct effect of being bilingual EP and bilingual LEP are also negative. Therefore, the resulting total effects shows that bilingual EP students have an initial science achievement that is around 2.53 points lower than monolingual students and bilingual LEP students have an initial science achievement that's around 8.02 points lower than monolingual students. Considering the initial gaps and growth rate estimated from the model, it would take bilingual EP students a little more than 3 years to fully close the initial gap in science achievement; however, it would take bilingual LEP students around 52 years to fully close the gap. This indicates that it is imperative to intervene in the educational process for bilingual LEP students so that they are not falling too far behind their monolingual peers.

CHAPTER VI. Discussions

6.1 Discussion of Results

Before entering kindergarten, bilingual LEP students have much lower academic achievement in all three subjects than their monolingual peers. While family and school characteristics are able to explain a portion of the achievement gaps at kindergarten entry, large gaps still exist even after controlling for family background and school characteristics. At the same time, bilingual LEP students also have much lower cognitive flexibility and working memory than their monolingual peers with comparable family background and school characteristics. The mediational analyses suggest that for all three subjects, the differences in the initial level of working memory and cognitive flexibility together contribute to a large proportion of the differences in the final test scores. For reading, 97% of the initial differences at kindergarten entry can be decomposed to the indirect effect through the differences in executive functions between bilingual LEP students and monolingual students at kindergarten entry. While such an estimate does not directly speak to a causal effect, it provides suggestive evidence that boosting executive functions might promote bilingual LEP students' academic achievement. For math, the differences in executive functions contribute to a gap that is even larger than the observed gap, which indicates that while some other unobserved factors associated with bilingual LEP students compensate for the disadvantage associated with lower executive functions, the lower executive function for bilingual LEP students are correlated with lower math scores. For science, the differences in executive function contribute to around 21% of the gap at kindergarten between bilingual LEP students and monolingual students.

These results indicate the importance of narrowing the achievement gap between bilingual LEP students and EP students before kindergarten entry. Moreover, the mediational analyses suggest that boosting executive function might be a very powerful way to boost academic achievement for bilingual LEP students, especially for reading and math. Preschool programs involving training that promotes executive function might be a good intervention for language minority LEP students.

If these gaps are already present at kindergarten entry, actions need to be taken to narrow these gaps in elementary years. For bilingual LEP students, while their achievement growth in all the three subjects are slower than that of monolingual students, the differences in growth rates are not significantly different. This indicates that, even though language minority Hispanic students do not have full English proficiency to access all school resources, they are able to maintain a comparable growth rate in achievement development. When family background and school characteristics are controlled, bilingual LEP students actually showed a faster growth rate in all three subjects. While the differences are not statistically significant, they indicate suggestive evidence that, given a comparable family background and school environment, bilingual LEP students are able to attain a growth rate in achievement that is faster than that of monolingual students. For example, when LEP students are provided with a stronger school environment, they might be able to catch up with their monolingual English proficient peers.

Bilingual LEP students also have a faster growth rate in working memory development than their monolingual peers given comparable family background and school characteristics. In fact, the indirect effect of being bilingual LEP through working memory growth on the achievement growth in all three subjects is significantly positive. This indicates a possibility that future interventions can boost bilingual LEP students' academic growth rate by working on improving their working memory development. Working memory training processes that have been proved effective might be employed to intervene in bilingual LEP students' education in elementary school years.

Before entering kindergarten, bilingual EP students are a little bit lower than monolingual students in achievement level in all three subjects. When family background and school characteristics are controlled, bilingual EP students have similar level of reading and math skills to monolingual students, but bilingual EP students are still a little bit behind monolingual students in science skills. At the same time, bilingual EP students' levels of executive function are almost comparable to that of monolingual students given the same family background and school characteristics. The analyses show that bilingual EP students' cognitive flexibility and working memory are a little bit lower than those of monolingual students, but the magnitude of differences is small and the results are not significant. The mediational analyses show that the differences in working memory and cognitive flexibility still contribute to the differences in the initial level of academic achievement in all three subjects between bilingual EP students and monolingual students, especially in reading and math.

This suggests that bilingual EP students lag behind monolingual students a little bit mainly because of the lower SES of their families. Because the mediational effect of executive function also holds for bilingual EP students, if they are given interventions to boost executive functions, it is likely that this boost would compensate the academic disadvantage associated with family background. Thus, interventions targeting bilingual EP students before kindergarten could consider executive function training programs. However, it is worth noting that the mediational effect through executive function on science achievement is modest at most. Therefore, other factors should be investigated in a search for possible mechanisms to boost science achievement.

After entering kindergarten, bilingual EP students' display faster achievement growth rates in both math and science than that of monolingual students, even though bilingual EP students have a lower level of family SES and attend schools with a less desirable learning environment. When family and school characteristics are controlled, bilingual EP students show even faster growth rates in all three subjects than that of monolingual students. At the same time, bilingual EP students also show faster growth in working memory development, which then contributes to a faster achievement growth in all three subjects. Indeed, for both reading and math, the indirect effect of being bilingual EP on achievement growth through the mediation of working memory growth is larger than the total observed effect. For science, the mediational effect is only around 43% of the total observed effect. Taken together, this indicates that interventions aimed at narrowing the achievement gap between bilingual EP students and monolingual students could try to target working memory development through the elementary years.

The results show that the mediational effect of executive function on the relationship between bilingualism and achievement is present in both bilingual EP students and bilingual LEP students. Future interventions targeting executive function training might benefit both groups of students. However, because bilingual LEP students lag behind monolingual students too much at the beginning of kindergarten, it is more important to intervene for bilingual LEP students than for bilingual EP students.

In addition to these practical implications, many results from my analyses further validated findings from previous studies. For one thing, the positive associations among the three constructs—bilingualism, executive function, academic achievement are replicated in results from my analyses. Moreover, by examining both the initial level and growth rate in the academic trajectories, my analyses add on to previous literature by showing that the cognitive and academic advantage associated with bilingualism is present in both the cross-sectional level and the growth rate. On the other hand, some of the results from my analyses are contrary to previous findings. For example, contrary to Kieffer (2008), lack of full English proficiency does not cause bilingual LEP students to have a slower growth rate in reading than monolingual students. Also, while previous research documenting the cognitive benefits of bilingualism emphasized that the advanced EF skills are mainly observed in bilingual students with full proficiency in both languages (Adesope et al, 2010), my results suggest that even bilingual LEP students have faster growth rates in working memory. In fact, bilingual LEP students have an even faster growth rate in working memory than bilingual EP students, which suggests the cognitive advantage in EF skills might not require full proficiency in both languages. Nonetheless, because the estimates from my analyses are susceptible to omitted variable bias, future causal studies are needed to further test to what extent the cognitive advantage in EF skills associated with bilingualism requires proficiency in both languages.

6.2 Limitations

While the analyses from this dissertation provide systematic estimates of the relationship between initial language status and achievement trajectories, as well as the mediational role of executive function in the relationship, the study has several limitations that needs to be noted in interpreting the results.

First and foremost, while the study is based on various supporting theoretical foundations about the relationship among bilingualism, achievement, and executive function, the analysis approach used in this dissertation is essentially correlational instead of causal. This has important implications for the interpretation of results in Part I and Part II. In Part I, the results show differences in academic trajectories by initial language status after controlling family SES and school characteristics. However, because many unobserved innate characteristics of the students are potentially confounding the relationship between language status and achievement trajectories, these differences should be interpreted as correlational associations rather than causal effects. As for Part II, the mediational analyses found important suggestive evidence on the extent to which executive function mediates the relationship between language status and achievement growth. However, the results should not be taken as causal because unobserved characteristics that could be correlated with both initial language status and executive function might exist. Therefore, the results from my analyses should be interpreted with caution, especially in the context of guiding future interventions. Future analyses with a stronger causal framework or with an experimental design are needed to further validate the correlational results from this dissertation.

Second, because the measurement of cognitive flexibility varied across different waves of data collection, the analyses in this dissertation were not able to formally test the mediational role of cognitive flexibility growth in the relationship between language status and achievement growth. I hope future studies can further test this by incorporating a consistent measurement in cognitive flexibility in the dataset. Furthermore, while ECLS-K has long been using the DCCS task to measure cognitive flexibility and the Numbers Reversed task to measure working memory, it is debatable to what extent these tasks accurately measure the specific discrete skills underlying executive functions. Indeed, some executive function tasks may often utilize more than one EF skill; for example, research (Zelazo, Muller, Frye, & Marcovitch, 2003) found that DCCS performance relies on working memory and inhibitory control, as well as attention shifting. Therefore, future studies should also try to identify the discrete cognitive skills involved in various executive function tasks using more accurate EF measurements, in order to better understand how these specific skills develop and affect academic performance.

6.3 Future Directions

The results from this study pose many important questions for future researchers to further investigate. These questions are important because they have the potential to advance our understanding of the relationship among bilingualism, executive function, and academic achievement for language minority students. Here I list a few further research questions as examples.

First, the pattern of the relationship involving the three main constructs (language status, achievement, executive function) for reading and math is different from that for science. In fact, there are also subtle differences between reading and math. For example, while bilingual EP students have a faster growth rate in math than monolingual students, they do not have a faster growth rate in reading. The differences in the pattern of relationships across different subjects could be due to differences underlying the way students approach the learning in different subjects. For example, the relationship between language status and reading development could be different from the relationship between language status and math development because math learning requires a different set of elements than reading learning. Similarly, the role of executive function in different subjects could also be different. Thus, future research should consider how the differences in learning models for different subjects might affect the relationship between language status and achievement in general.

Second, a comparison between the bilingual EP group and bilingual LEP group from this dissertation shows that the bilingual LEP group has a lower level of initial executive function but the bilingual LEP group also has a faster growth in working memory. And these differences then translate to different indirect effects given the same direct effect of executive function on initial achievement level and achievement growth rate. This is built on the assumption that the relationship between executive function and achievement level/growth is the same for both bilingual EP and bilingual LEP students. In reality, however, there might be a possibility that the level of English proficiency could moderate the relationship between executive function and achievement. For example, the way working memory growth benefits achievement growth might be more likely to happen when students are fully proficient in both languages. Thus, future research may further investigate this assumption and test to what extent the language status (the level of proficiency in two languages) might moderate the way executive function benefits academic achievement.

Finally, this dissertation limited the analyses to Hispanic students only. This has several advantages, including focusing the interpretability of the results to Hispanic population only and thus deliver a clear applicability; ruling out the "cultural channel" effect by including a homogeneous minority language. However, future studies should also consider students speaking other minority languages to test the robustness of the results. Because the correlation between executive function and bilingualism is investigated among a variety of bilingual students, including Asian students, Arabic students, and so forth, it is important for researchers to test across these different groups of students. This will not only help validate the relationships we have already found, but also improve our understanding of the relationship among bilingualism, executive function, and academic achievement in general.

Appendix tables

Appendix table 1. Differences in learning trajectories including coefficients for covariates – unstandardized coefficients

	Reading		Math		Science	
Whether include controls	No	Yes	No	Yes	No	Yes
Intercept						
bipro	-2.107***	0.0597	-2.242***	0.0320	-4.086***	-2.434***
	(0.397)	(0.414)	(0.389)	(0.407)	(0.205)	(0.211)
binonpro	-11.17***	-8.109***	-9.966***	-6.791***	-9.717***	-7.369***
	(0.431)	(0.479)	(0.420)	(0.468)	(0.230)	(0.249)
constant	54.85***	55.44***	36.38***	36.62***	30.44***	33.58***
	(0.304)	(1.275)	(0.264)	(1.245)	(0.127)	(0.647)
Socioeconomic status		4.194***		4.050***		2.102***
		(0.302)		(0.296)		(0.155)
Whether attended a public school		1.825*		0.247		-0.375
		(0.834)		(0.821)		(0.427)
Average school facility		-0.455		0.0679		-0.0265
		(0.261)		(0.256)		(0.134)
Teacher reported school environment		0.893*		1.244**		0.618**
		(0.430)		(0.423)		(0.220)
Average percent of minority		0.0159		0.0248**		-0.0320***
		(0.009)		(0.009)		(0.005)
Average percent of free lunch eligible students		-0.0125		-0.0291*		-0.00353
		(0.012)		(0.012)		(0.006)
Average percent of ELL students		-0.0017		-0.000753		0.00162
		(0.010)		(0.010)		(0.005)
Whether received title I		-0.422		-0.618		-0.264
		(0.602)		(0.591)		(0.308)
Whether received title III		0.5		1.189***		0.252
		(0.368)		(0.361)		(0.188)
Slope						
bipro	-0.0157	0.136	0.0570	0.174*	0.276***	0.385***
	(0.0748)	(0.0814)	(0.0665)	(0.0725)	(0.0505)	(0.0546)
binonpro	-0.0614	0.155	-0.00742	0.145	-0.0738	0.0612
	(0.0806)	(0.0933)	(0.0708)	(0.0824)	(0.0558)	(0.0636)
constant	8.770***	8.873***	9.001***	8.685***	3.969***	3.495***
	(0.0748)	(0.259)	(0.0525)	(0.229)	(0.0320)	(0.172)
Socioeconomic status		0.0584		0.163**		0.230***

	(0.060)	(0.053)	(0.040)
Whether attended a public school	-0.118	0.550***	0.389***
	(0.173)	(0.155)	(0.118)
Average school facility	0.113*	0.0671	0.0507
	(0.051)	(0.045)	(0.035)
Teacher reported school environment	0.0288	0.0493	0.161**
	(0.088)	(0.079)	(0.060)
Average percent of minority	-0.00146	-0.00420*	0.00338**
	(0.002)	(0.002)	(0.001)
Average percent of free lunch eligible students	-0.00510*	-0.0033	-0.00510**
	(0.002)	(0.002)	(0.002)
Average percent of ELL students	-0.00183	0.00365*	0.00262
	(0.002)	(0.002)	(0.001)
Whether received title I	0.0188	0.0426	-0.0487
	(0.116)	(0.102)	(0.078)
Whether received title III	0.0662	-0.0487	0.0686
	(0.071)	(0.063)	(0.047)

Notes. There are two columns of coefficients for each subject. the left column does not control for family and school characteristics, representing the simple, unconditional growth model of test scores. The right column controls for family and school characteristics, representing the conditional growth model where family and school characteristics are estimated to explain the initial level and growth rate of test scores. The sample size is 4092 with 1959 monopro, 1191 bipro, and 941 binonpro. The missing values are handled by the maximum likelihood with missing values (mlmv) options in Stata SEM command. The reference group is monolingual English proficient students. All of the variables used are in raw scales.

Appendix table 2. Differences in learning trajectories including coefficients for covariates -- standardized coefficients

	Reading		Math		Science	
Whether include controls	No	Yes	No	Yes	No	Yes
Intercept						
bipro	-0.0871***	0.00247	-0.0884***	0.00126	-0.334***	-0.199***
	(0.0164)	(0.0171)	(0.0153)	(0.0160)	(0.0168)	(0.0172)
binonpro	-0.461***	-0.335***	-0.393***	-0.268***	-0.794***	-0.602***
	(0.0178)	(0.0198)	(0.0166)	(0.0184)	(0.0187)	(0.0203)
constant	-0.983***	-1.113***	-0.977***	-1.051***	-0.583***	-0.630***
	(0.0126)	(0.0455)	(0.0104)	(0.0420)	(0.0104)	(0.0452)
Socioeconomic status		0.120***		0.110***		0.119***
		(0.009)		(0.008)		(0.009)
Whether attended a public school		0.0754*		0.00975		-0.0306
		(0.035)		(0.032)		(0.035)

Average school facility		-0.0128		0.00183		-0.00147
		(0.007)		(0.007)		(0.007)
Teacher reported school environment		0.0150*		0.0199**		0.0205**
		(0.007)		(0.007)		(0.007)
Average percent of minority		0.0182		0.0271**		-0.0723***
		(0.011)		(0.010)		(0.011)
Average percent of free lunch eligible students		-0.0142		-0.0316*		-0.00795
		(0.014)		(0.013)		(0.014)
Average percent of ELL students		-0.00161		-0.000678		0.00302
		(0.010)		(0.009)		(0.010)
Whether received title I		-0.0174		-0.0244		-0.0216
		(0.025)		(0.023)		(0.025)
Whether received title III		0.0207		0.0469***		0.0206
		(0.015)		(0.014)		(0.015)
Slope						
bipro	-0.000648	0.00563	0.00225	0.00687*	0.0225***	0.0314***
	(0.00309)	(0.00336)	(0.00262)	(0.00286)	(0.00413)	(0.00446)
binonpro	-0.00254	0.00642	-0.000292	0.00571	-0.00603	0.00500
	(0.00333)	(0.00385)	(0.00279)	(0.00325)	(0.00456)	(0.00519)
constant	0.362***	0.362***	0.355***	0.332***	0.324***	0.289***
	(0.00309)	(0.00929)	(0.00207)	(0.00776)	(0.00261)	(0.0121)
Socioeconomic status		0.00167		0.00443**		0.0130***
		(0.002)		(0.001)		(0.002)
Whether attended a public school		-0.00489		0.0217***		0.0318***
		(0.007)		(0.006)		(0.010)
Average school facility		0.00317*		0.0018		0.00282
		(0.001)		(0.001)		(0.002)
Teacher reported school environment		0.000482		0.000788		0.00533**
		(0.001)		(0.001)		(0.002)
Average percent of minority		-0.00168		-0.00459*		0.00765**
		(0.002)		(0.002)		(0.003)
Average percent of free lunch eligible students		-0.00581*		-0.00359		-0.0115**

	(0.003)	(0.002)	(0.004)
Average percent of ELL students	-0.00173	0.00329*	0.00489
	(0.002)	(0.002)	(0.003)
Whether received title I	0.000778	0.00168	-0.00397
	(0.005)	(0.004)	(0.006)
Whether received title III	0.00273	-0.00192	0.0056
	(0.003)	(0.002)	(0.004)

Notes. There are two columns of coefficients for each subject. the left column does not control for family and school characteristics, representing the simple, unconditional growth model of test scores. The right column controls for family and school characteristics, representing the conditional growth model where family and school characteristics are estimated to explain the initial level and growth rate of test scores. The sample size is 4092 with 1959 monopro, 1191 bipro, and 941 binonpro. The missing values are handled by the maximum likelihood with missing values (mlmv) options in Stata SEM command. The reference group is monolingual English proficient students. All of the variables are standardized except for dummy variables. Specifically, the test scores of reading, math, and science are pooled and standardized across all waves; time-invariant covariates are standardized across the whole analysis sample.

Appendix table 3a. Latent growth curve mediation model for reading – standardized effects

	Independent -> Mediator	Mediator -> Dependent	Indirect effect	Direct effect	Total effect
Slope of WM					
bipro	0.010**	0.673***	0.006**	-0.001	0.005
	(0.005)	(0.081)	(0.003)	(0.004)	(0.003)
binonpro	0.043***	0.673***	0.029***	-0.023***	0.006
	(0.005)	(0.081)	(0.005)	(0.006)	(0.004)
Intercept of WM					
bipro	-0.021	0.680***	-0.015	0.023	0.007
	(0.026)	(0.017)	(0.018)	(0.019)	(0.018)
binonpro	-0.454***	0.680***	-0.324***	-0.009	-0.333***
	(0.029)	(0.017)	(0.021)	(0.023)	(0.021)
Initial level of CF					
bipro	-0.028	0.031***	-0.015	0.023	0.007
	(0.042)	0.006	(0.018)	(0.019)	(0.018)
binonpro	-0.516***	0.031***	-0.324***	-0.009	-0.333***
	(0.048)	0.006	(0.021)	(0.023)	(0.021)

Note. The intercept of working memory growth and the initial level of cognitive flexibility are set to mediate the relationship between language status and the intercept of reading growth; the slope of working memory growth is set to mediate the relationship between language status and the slope of reading growth. Family SES and school characteristics are included in the model as covariates. All continuous variables are standardized.

Appendix table 3b. Latent growth curve mediation model for math – standardized effects

	Independent -> Mediator	Mediator -> Dependent	Indirect effect	Direct effect	Total effect

Slope of WM					
bipro	0.010**	0.720***	0.007**	-0.001	0.006**
	(0.005)	(0.066)	(0.003)	(0.004)	(0.003)
binonpro	0.042***	0.720***	0.030***	-0.025***	0.006
	(0.005)	(0.066)	(0.005)	(0.005)	(0.003)
Intercept of WM					
bipro	-0.024	0.719***	-0.019	0.026	0.007
	(0.025)	(0.015)	(0.018)	(0.016)	(0.016)
binonpro	-0.456***	0.719***	-0.353***	0.083***	-0.270***
	(0.029)	(0.015)	(0.022)	(0.020)	(0.019)
Initial level of CF					
bipro	-0.031	0.048***	-0.019	0.026	0.007
	0.042	0.005	(0.018)	(0.016)	(0.016)
binonpro	-0.514***	0.048***	-0.353***	0.083***	-0.270***
	0.048	0.005	(0.022)	(0.020)	(0.019)

Note. The intercept of working memory growth and the initial level of cognitive flexibility are set to mediate the relationship between language status and the intercept of math growth; the slope of working memory growth is set to mediate the relationship between language status and the slope of math growth. Family SES and school characteristics are included in the model as covariates. All continuous variables are standardized.

Appendix table 3c. Latent growth curve mediation model for science – standardized effects

	Independent -> Mediator	Mediator -> Dependent	Indirect effect	Direct effect	Total effect
Slope of WM					
bipro	0.008	1.229***	0.010	0.022**	0.032***
	(0.005)	(0.223)	(0.006)	(0.007)	(0.004)
binonpro	0.041***	1.229***	0.050***	-0.043***	0.008
	(0.005)	(0.223)	(0.011)	(0.012)	(0.005)
Intercept of WM					
bipro	-0.022	0.474***	-0.012	-0.192***	-0.204***
	(0.026)	(0.021)	(0.012)	(0.019)	(0.019)
binonpro	-0.454***	0.474***	-0.245***	-0.407***	-0.653***
	(0.029)	(0.021)	(0.017)	(0.024)	(0.022)
Initial level of CF					
bipro	-0.032	0.059***	-0.012	-0.192***	-0.204***
	(0.042)	(0.008)	(0.012)	(0.019)	(0.019)
binonpro	-0.517***	0.059***	-0.245***	-0.407***	-0.653***
	(0.048)	(0.008)	(0.017)	(0.024)	(0.022)

Note. The intercept of working memory growth and the initial level of cognitive flexibility are set to mediate the relationship between language status and the intercept of science growth; the slope of working memory growth is set to mediate the relationship between language status and the slope of science growth. Family SES and school characteristics are included in the model as covariates. All continuous variables are standardized.

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