Do English and Spanish-Language Adapted Mathematics Items Function Differently?
Investigating Differential Item Functioning and Item Bias Within a Regression Discontinuity
Design Framework to Control for Selection Bias

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Abstract

When measuring academic skills among students whose primary language is not English, standardized assessments are often provided in languages other than English (Tabaku, Carbuccia-Abbott, & Saavedra, 2018). The degree to which alternate-language test items function equivalently must be evaluated, but traditional methods of investigating measurement equivalence may be confounded by group differences on characteristics other than ability level and language form. The primary purposes of this study were to investigate differential item functioning (DIF) and item bias across Spanish and English forms of an assessment of early mathematics skills. Secondary purposes were to investigate the presence of selection bias and demonstrate a novel approach for investigating DIF that uses a regression discontinuity design framework to control for selection bias. Data were drawn from 1,750 Spanish-speaking Kindergarteners participating in the Early Childhood Longitudinal Study, Kindergarten Class of 1998-99, who were administered either the Spanish or English version of the mathematics assessment based on their performance on an English language screening measure. Results indicated a minority of items functioned differently across the Spanish and English forms, and subsequent item content scrutiny indicated no plausible evidence of item bias. Evidence of selection bias—differences between groups in SES, age, and country of birth, in addition to mathematics ability and form language—highlighted limitations of a traditional approach for investigating DIF that only controlled for ability. Fewer items exhibited DIF when controlling for selection bias (11% vs. 25%), and the type and direction of DIF differed upon controlling for selection bias.

Keywords: *dual language learners, differential item functioning, mathematics, regression discontinuity design*

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Despite evidence of significant progress in the education of dual language learners (DLLs; i.e., children who speak a language other than English at home), significant achievement gaps remain in mathematics between monolingual children and DLLs (Kieffer & Thompson, 2018). Prior research indicates that achievement gaps begin early in life and grow throughout the elementary years. Specifically, Kieffer (2008) reported that DLLs who enter kindergarten with typical levels of English proficiency have developmental trajectories of academic skills that do not diverge from those of monolingual children. In contrast, DLLs who enter kindergarten with limited English proficiency have significantly slower development of academic skills than do monolingual children, resulting in large achievement gaps by the time children reach late elementary school. Additionally, evidence indicates that early mathematics skills are strongly associated with high school mathematics achievement, even after controlling for reading skills, cognitive ability, and socioeconomic status (e.g., Watts, Duncan, Siegler, & Davis-Kean, 2014). Consequently, it is critical that researchers identify DLLs who are at risk for mathematics learning difficulties early in life so that additional supports can be provided to those children to prevent them from falling behind their monolingual peers.

One issue that is central to accurate identification of children at risk for mathematics learning disabilities is the use of achievement tests that are supported by strong reliability and validity evidence. Extant evidence indicates that assessing general cognitive ability does not improve the ability to distinguish presence of or risk for learning disabilities, and current best practice is to rely on direct assessment of academic achievement (e.g., norm- or criterion-

referenced mathematics assessments), alongside evaluations of student responsiveness to instruction, to identify potential learning disabilities (Fletcher & Miciak, 2017; Miciak, Taylor, Denton, & Fletcher, 2015). However, assessment of mathematics achievement among DLLs is complicated by children's varied English proficiency (Abedi, 2002; Solano-Flores & Li, 2008). Some DLLs may have typical levels of English proficiency, allowing them to demonstrate knowledge and skills in mathematics through English-language assessments. Other DLLs have limited English proficiency, and poor performance on English mathematics achievement tests may reflect limitations in language ability rather than deficits in mathematics skills. One common approach to mathematics assessment for DLLs with limited English proficiency is to administer assessments adapted to children's home language. However, even when assessments are available in children's home language (e.g., Spanish), the equivalence of these adapted tests may be under-evaluated and under-reported. Validity evidence to support alternate-language adaptations of English mathematics achievement tests is thus lacking.

To address this limitation, the current study evaluated construct validity evidence of the Spanish-adapted kindergarten mathematics assessment used in the Early Childhood Longitudinal Study, Kindergarten Class of 1998-99 (ECLS-K). Specifically, we used differential item functioning (DIF) analysis to evaluate whether, among Spanish-speaking DLLs, the Spanish-adapted items measured the same construct and were on the same scale (i.e., had equivalent item difficulty) as the items on the English version of the mathematics assessment. Subsequently, we conducted item content scrutiny to determine whether items flagged for DIF indicated item bias. Notably, traditional methods for investigating DIF only control for ability level; if the two groups differ on characteristics other than ability level and assessment form/English language proficiency, inferences regarding DIF (and item bias) will be confounded by selection bias.

Therefore, we also investigated the presence of selection bias and compared DIF and item bias results from a traditional method for investigating DIF with results from a novel approach that controls for selection bias by drawing on a regression discontinuity design framework.

Assessment of Mathematics Achievement for Dual Language Learners

Level of English proficiency represents a critical barrier to accurately discriminating DLLs with and without learning difficulties. Limited English proficiency hinders children's ability to understand and respond accurately to mathematics questions presented in English, even when children possess adequate mathematics skills. Because of difficulties related to assessment of DLLs, some evidence indicates that DLLs are often under-identified as having learning difficulties (Morgan et al., 2015), especially in the early elementary years when teachers are hesitant to refer children with limited English proficiency for special education evaluations (Samson & Lesaux, 2009). Conversely, DLLs are over-identified as having learning difficulties in the late elementary years and are identified as needing special education later than are monolingual children (Samson & Lesaux, 2009; Sullivan, 2011). Disproportionate representation of DLLs in special education has important implications for student achievement, as many DLLs with learning difficulties may not be receiving the supports they need to succeed in the early school years.

Federal regulation requires that education agencies provide accommodation for DLLs when administering assessments of academic achievement. According to the Individuals with Disabilities Education Act (2004), evaluation of learning disabilities for DLLs should be "provided and administered in the child's native language...in the form most likely to yield accurate information on what the child knows and can do academically." Similarly, the Every Student Succeeds Act (2015) specifies that states must make efforts to provide assessments in

children's home language when there is a "significant" prevalence of a given language.

Additional recommendations for DLLs have included conducting assessments in both the home language and English, using informal, curriculum-based assessments, dynamic assessment procedures, or portfolio assessments (e.g., Spinelli, 2008).

Assessment accommodations for DLLs must be supported by both validity and effectiveness evidence (Abedi, Zhang, Rowe, & Lee, 2020). According to Abedi et al., accommodations are effective when they make assessments more accessible to the test takers. Robinson (2010) evaluated the effectiveness of the Spanish-language adaptation of the ECLS-K kindergarten mathematics assessment, using a regression discontinuity approach to control for selection bias, and reported that English language learners who completed the mathematics achievement test in Spanish scored significantly higher than English language learners who completed the mathematics assessment in English at two out of three assessment points (spring of kindergarten and first grade, but not fall of kindergarten). Furthermore, effect sizes reported across Spanish and English mathematics assessments were large (i.e., $d_s > .85$). This indicates that, as an accommodation, use of the Spanish-language form of the assessment was effective, as children were better able to demonstrate their mathematics knowledge when given the Spanish assessment. However, effectiveness evidence is only meaningful to the extent that the accommodation is supported by validity evidence. Validity of accommodations is established when it is determined that the accommodation does not alter the construct being measured and does not provide an unfair advantage on the assessment (Abedi et al., 2020). It is possible, for example, that group differences observed by Robinson exist not because the English assessment underestimates children's true ability, but because items on the Spanish-adapted assessment function differently (are less difficult) than the corresponding English items, controlling for

underlying mathematics ability. If this were the case, Spanish-speakers assigned to the Spanish form of the assessment would have an unfair advantage over Spanish speakers assigned to the English form. Thus, more research is needed to determine the validity of assessment accommodations (such as alternate-language translations) prior to evaluating the effectiveness of those accommodations.

Differential Item Functioning

Translating mathematics assessments from one language to another and using the translated tests to measure achievement among DLLs requires the assumption that the adapted-language items operate equivalently to the English-language items. However, this assumption may be violated in practice. For example, a language-based word problem may have information that does not translate directly to another language or is not culturally relevant to certain groups of children. Holding achievement level constant, items that operate differently across forms are said to demonstrate DIF (Embretson & Reise, 2000).

Test items can demonstrate one of two types of DIF, uniform and non-uniform DIF (Güler & Penfield, 2009). Items that demonstrate uniform DIF are significantly more difficult on one form of the assessment than the other, holding ability level constant. In other words, for a mathematics item that displays uniform DIF, two test takers who complete different forms of the assessment have different probabilities of responding to the item correctly, despite having the same underlying mathematics ability. Non-uniform DIF occurs across assessment forms when a test item is more strongly associated with the underlying construct and better able to differentiate among different ability levels for one form of the assessment than the other. For example, an item that is poorly translated may not distinguish well between test takers with different ability levels. In this case, DIF is said to be non-uniform because the difference in difficulty of the item

across assessment forms varies across the range of ability (e.g., for test takers with low levels of mathematics ability the item is more difficult on the Spanish assessment but for test takers with high levels of mathematics ability the item is more difficult on the English assessment). There are multiple approaches for evaluating DIF, and for this study we implement a probit regression approach to detecting uniform and non-uniform DIF (see Method section for details).

Items and tests that demonstrate substantial amounts of DIF may be biased in favor of one group or assessment form, but the presence of DIF alone does not necessarily indicate item or test bias (e.g., Cho, Suh, & Lee, 2016). To make the assertion of bias, item content must be examined to determine whether there is a theoretical basis for the existence of bias in the presence of DIF. If items demonstrating DIF are assessing constructs other than the construct intended, it may be concluded that the item is biased (Penfield & Lam, 2000). For example, a word problem on a mathematics assessment may measure children's language or reading skills, in addition to their mathematics skills (e.g., Goodrich & Namkung, 2019). Therefore, word problems may have the potential to demonstrate bias across groups with differing levels of language or reading ability, such as when comparing performance across monolingual children and DLLs, as differences in performance across items may not represent differences in mathematics ability.

Prior research examining DIF for DLLs has primarily compared item functioning across monolingual English-speaking children and DLLs in which both groups completed the assessment in English (Farrington, Lonigan, Phillips, Farver, & McDowell, 2015; Goodrich, Lonigan, & Alfonso, 2019; Kamata, Chaimongkol, Genc, & Bilir, 2005; Lakin, Elliott, & Liu, 2012; Mahoney, 2008; Martiniello, 2009; Ockey, 2007; Snetzler & Qualls, 2000). Several of these studies have not found substantial evidence of DIF across DLLs and monolingual children

on achievement tests (Lakin et al., 2012; Mahoney, 2008; Martiniello, 2009; Ockey, 2007).

Other studies have reported that numerous test items demonstrate DIF (e.g., Farrington et al., 2015; Goodrich et al., 2019; Kamata et al., 2005; Snetzler & Qualls, 2000); however, these studies have generally reported that DIF did not systematically favor one group over the other across items, providing little indication of test bias.

Despite a lack of evidence of item and test bias across monolingual children and DLLs for achievement assessments administered in English, it is possible that DIF and bias exist across adapted-language and original English-language versions of tests used to evaluate academic achievement. For example, if the English language proficiency cut score used to determine language of assessment is too low, then items on the English version may be more difficult than items on the adapted-language form when evaluating DIF among DLLs. Of particular relevance to this study, in comparing the English-language version of the mathematics assessment to the Spanish-adapted language version, test developers for the ECLS-K study concluded that the items operated similarly across forms (U.S. Department of Education, 2002). However, this comparison was based on a heterogeneous sample in which the group who received the English-language version, which included monolingual English speakers, Spanish-speaking DLLs, and DLLs with other home languages who passed the English language proficiency screener, likely differed in many ways from the Spanish-speaking DLLs who did not pass the screener and thus received the Spanish-adapted assessment. Given this threat of selection bias, a more controlled approach would be to evaluate DIF across assessment forms specifically among the Spanish-speaking children in the sample. Embedding a quasi-experimental design (regression discontinuity design) in the evaluation of DIF would offer even greater control, as discussed in the next section.

Controlling for Selection Bias in Evaluation of Differential Item Functioning: Embedding Regression Discontinuity Designs (RDD)

When administering alternate-language forms of mathematics assessments for DLLs, typical practice is to screen children for English language proficiency and administer the alternate-language version to children who score below a certain cutoff and the English-language version to children above that cutoff. The assumption underlying this practice is that the two groups of DLLs differ in their level of English proficiency but are otherwise similar (i.e., there is no selection bias). However, it is possible that DLLs with lower levels of English proficiency differ significantly from DLLs with typical levels of English proficiency on various dimensions (e.g., socioeconomic status, reading skills, nonverbal cognitive ability). Using a traditional method for investigating DIF that controls for ability level on the underlying construct but does not account for differences on other relevant variables may be inappropriate, as assignment to test form is potentially confounded by selection bias. In this situation, it is not possible to know whether DIF (and associated item/test bias) is solely due to form-related differences or due to other differences between groups.

To control for potential selection bias in the evaluation of DIF across assessment forms for DLLs, we propose a novel approach that capitalizes on naturally occurring regression discontinuity designs (RDD; Imbens & Lemieux, 2008) present in this type of assessment context. RDD is considered to be the most rigorous alternative to randomized controlled trial design to facilitate causal inference (Bloom, 2012; Cook, 2008). In RDD, treatment assignment is determined by a cutoff on an assignment measure that typically assesses the participants' need for the treatment. For example, in the present study, an English language proficiency screener is used to assign Spanish-speaking DLLs to either an English or Spanish-adapted version of a

mathematics assessment. If the “treatment” (language form) has an impact on the outcome (in this study, mathematics item response), then a discontinuity in the regression relationship between the assignment variable (the English language proficiency score) and the mean outcome (the item response) occurs at the cutoff of the assignment variable (at the score that defines English proficiency). Figure 1, for example, illustrates a discontinuity in the relationship between English proficiency score and SES at the cutoff for defining English proficiency, suggesting systematic differences in SES between DLLs assigned to the English vs. Spanish-adapted form.

The major advantage of RDD stems from its ability to estimate an unbiased causal estimate *at the cutoff*. This is because the participants in the treatment and control groups near the cutoff are assumed to be comparable such that there are no systematic differences between participants with similar values on the assignment variable at the cutoff, except in terms of treatment assignment status. In our proposed approach for investigating DIF (and item/test bias), we control for selection bias by embedding an RDD within an existing framework for evaluating DIF. Specifically, by incorporating RDD terms into a traditional probit regression model for investigating DIF, we conditionalize estimates of DIF at the English language proficiency cutoff of the language screener used to assign children to the English versus Spanish version of the mathematics achievement assessment in the ECLS-K study. Thus, characteristics of children who are clustered just above and below the cut-point of the language screener should be comparable, controlling for any existing selection bias across children who receive different versions of the test. The control of selection bias at the cutoff using RDD theoretically allows for unbiased causal conclusions to be drawn regarding the source of any observed DIF (i.e., the language form of the assessment).

Current Study

The primary purposes of this study were to investigate DIF and item bias across Spanish and English forms of an assessment of early mathematics skills. Secondary purposes were to investigate the presence of selection bias and demonstrate a novel approach for investigating DIF that uses a regression discontinuity design framework to control for selection bias. We addressed the following research questions:

1. Do any mathematics items demonstrate DIF across the Spanish- and English-language administrations using:
 - a. a traditional approach for evaluating DIF that controls for achievement level but ignores other sources of selection bias?
 - b. an RDD approach for evaluating DIF that controls for achievement level and other sources of selection bias?
2. Among items that demonstrate DIF, are there any patterns that suggest plausible item/test bias:
 - a. for items flagged as showing DIF using the traditional approach?
 - b. for items flagged as showing DIF using the RDD approach?

When using a traditional approach, we expected there to be substantial DIF across assessment forms, primarily because children who completed different versions of the assessment likely differed on many other dimensions besides achievement level and English language proficiency.

When using an RDD approach, we expected to observe less evidence of DIF because the potential threat of selection bias would be better controlled. We did not formulate specific a priori hypotheses regarding patterns of potential item/test bias, as we were not able to statistically evaluate bias. Rather, we performed a post hoc, exploratory, subjective evaluation of

item content to search for potential patterns across items that may explain observed DIF.

Method

Data Source

Secondary data were drawn from the ECLS-K restricted-use dataset (ECLS-K; U.S. Department of Education, 2000). The authors received a certification of exemption from their university's Institutional Review Board to carry out the secondary analysis. The ECLS-K, sponsored by the National Center for Education Statistics within the U.S. Department of Education, followed a U.S. nationally representative sample of 21,260¹ children from kindergarten in 1998-99 through 8th grade in 2006-07 with the purpose of describing and identifying correlates of children's cognitive/academic, socioemotional, and physical development. A stratified, multistage (geographic areas/counties, schools, children) probability sampling design was used to select participants. Data collection spanned multiple sources and methods, including direct child assessments, child questionnaires, parent interviews, and teacher and school administrator questionnaires.

Participants

The current study used kindergarten data from 1,750 children who were identified as having a home language of Spanish, had base year panel weights, and had mathematics and oral English language proficiency scores (see *Measures and Variables*). Home language was determined by the ECLS-K team by checking school records, and in the absence of this information, by consulting the child's teacher to determine whether: 1) The child spoke a language other than English; 2) The child's family members spoke a language other than English; and/or 3) The child had been observed conversing in a language other than English

¹ All unweighted sample sizes are rounded to the nearest 10 per Institute of Education Sciences (IES) restricted-use data requirements.

(U.S. Department of Education, 2000). If one or more criteria were met, teachers were asked to specify the non-English language. Children with an IEP-listed accommodation of Braille, enlarged print, or sign language, or with an IEP that indicated they could not participate in standardized assessments, were excluded from direct cognitive testing and thus excluded from the current study. Less than 1% of children with a home language of Spanish and base year panel weights had missing mathematics scores and English proficiency scores.

Weighted descriptive statistics for the current study's target subpopulation of kindergarteners ($N = 381,773$) versus the total population of kindergarteners ($N = 3,865,945$) are as follows: 50.1% vs. 51.3% male; 7.2% vs. 14.7% with a parent-reported disability; 87.8% vs. 97.3% born in the U.S.; $M = 67.69$ ($SD = 4.35$) vs. $M = 68.50$ ($SD = 4.45$) months of age at the fall kindergarten assessment wave; $M = -0.63$ ($SD = 0.62$) vs. $M = -0.03$ ($SD = 0.79$) household SES composite score; and $M = -1.55$ ($SD = 0.42$) vs. $M = -1.19$ ($SD = 0.48$) fall kindergarten mathematics IRT theta score.

Measures and Variables

Unless otherwise noted variables were drawn from fall of kindergarten (Wave 1).

Mathematics achievement. The ECLS-K design team, drawing heavily on the “*Mathematics Framework for the 1996 National Assessment of Educational Progress* (National Assessment Governing Board, 1996)” (p. 2-7; U.S. Department of Education, 2002), developed a direct assessment of kindergarten mathematics achievement that covered five content strands: 1) Number sense, properties, and operations (NSPO; $\approx 73\%$ of items included in the kindergarten scale scores); 2) Measurement (MEAS; $\approx 4\%$); 3) Geometry and spatial sense (GSS; $\approx 4\%$); 4) Data analysis, statistics and probability (DSP; $\approx 8\%$); and 5) Patterns, algebra, and functions (PAF; $\approx 12\%$). Items were drawn from existing measures, including the Peabody Individual

Achievement Test-Revised (PIAT-r; Markwardt, 1989); Primary Test of Cognitive Skills (PTOC; Huttenlocher & Levine, 1990); Test of Early Mathematics Ability (TEMA-2; Ginsburg & Baroody, 1990), and Woodcock Johnson Tests of Achievement-R (WJ-R; Woodcock & Bonner, 1989), as well as newly developed by curriculum specialists and teachers. A Spanish version of the assessment was developed using forward- and back-translation procedures, with expert feedback provided by mathematicians whose native language was Spanish (U.S. Department of Education, 2002). Of the 1,750 children in the current study with a home language of Spanish, 1020 (58%) completed the Spanish version of the mathematics assessment. Both multiple-choice and open-ended response formats were used. All items were designed to be answered orally or by pointing to the answer.

The kindergarten mathematics assessment was untimed and individually administered using an adaptive two-stage design in which all children received a common core of 16 items (plus an additional 2 practice items) that was then used to route them to a low difficulty form (18 items), medium form (23 items), or high form (31 items). One of the open-ended routing items was subsequently divided into two distinct items at the time of scoring, for a total of 17 non-practice routing items. Among children in the target subsample, 95% were routed to the low form, 4% the medium form, and <1% the high form, compared to 77% of children in the total sample who were routed to the low form, 17% the medium form, and 6% the high form (p. 73; U.S. Department of Education, 2002). The full assessment included 64 scored items, of which 51 were used in the construction of the kindergarten scale scores and the remaining were linking items used only for vertical scaling purposes.

ECLS-K psychometricians calibrated the mathematics items by applying a multiple-group three-parameter logistic item response theory (IRT) model with Bayesian priors to a

pooled dataset containing responses to all mathematics items across all grade levels. IRT theta scores were generated using expected *a posteriori* estimation. Estimated reliability of the Wave 1 theta scores, using data from all children in the sample, was .92 (U.S. Department of Education, 2002). Mathematics scores were strongly correlated with reading ($r = .77$) and general knowledge ($r = .64$) scores at Wave 1.

The current study evaluated DIF for 28 items that were included on the routing or low form and were used in the construction of the kindergarten scale scores (the 2 practice items and the 7 items on the routing form that were used only for linking purposes were not evaluated). Descriptive statistics for these items are presented in Table 1. Based on data from the target subsample, the proportion correct ranged from .05 to .96 across items with $M = .42$ ($SD = .24$), and the point-biserial correlation between the item and overall mathematics theta score ranged from .16 to .71 with $M = .39$ ($SD = .15$). Sample size varied slightly across analyses as a function of the items' form assignment (routing vs. low form vs. low and medium and/or high form) and due to item-level missingness that occurred when children refused to answer or said "I don't know." This latter reason for missingness was rarely observed (maximum = 3.4% and median = 0.1% across the 28 items). Too few children in the target subsample were routed to the medium and high forms to facilitate DIF analyses of items that only appeared on those forms.

[INSERT TABLE 1 ABOUT HERE]

Oral English language proficiency. Children's oral English proficiency was used to route them to either the English or Spanish version of the mathematics assessment (U.S. Department of Education, 2002). Conceptualized by the ECLS-K design team in consultation with an expert panel, proficiency was measured via performance on the Oral Language Development Scale (OLDS), an untimed and individually administered direct assessment. The

OLDS comprises three subtests of the PreLAS 2000 (Duncan & DeAvila, 1998): 1) “Simon Says,” a 10-item measure of receptive language with a maximum score of 10; 2) “Art Show,” a 10-item measure of expressive language (picture vocabulary) with a maximum score of 10; and 3) “Let’s Tell Stories,” a measure of receptive and expressive language based on the retelling of 2 story prompts with a maximum score of 40. English proficiency was defined as a total OLDS raw score ≥ 37 , which “was based on results of a national norming sample for PreLAS, extrapolated to the three selected subtests” (p. 2-22; U.S. Department of Education, 2002). Assessors had to achieve 90% accuracy on a set of training stories in order to administer the OLDS. Ongoing interrater reliability was evaluated by recoding 10% of each assessor’s stories, where perfect score agreement was achieved for 66% of these stories. For the remaining stories, agreement was achieved by two of three coders. Estimated split-half reliability of the Wave 1 scores, using data from all children in the sample with a home language other than English, was .97.

Demographic characteristics. Child demographic characteristics, including gender, date of birth (used to construct age in months at time of mathematics assessment), disability status (with disability vs. not), country of birth reported at Wave 2 (U.S. born vs. not), and household SES, were obtained via parent interview. Disability status and household SES were composite variables created by the ECLS-K team. A child was categorized as having a disability if the parent reported a professional diagnosis related to the child’s difficulty with paying attention, learning, activity level, coordination in moving limbs, communication, hearing, and/or seeing, and/or reported that the child had received therapy services for a disability. Household SES combined information about the education level and occupational prestige of the child’s mother and father figures (Wave 1) and household income (Wave 2). Hot deck imputation was used to

impute scores when one or more of the SES indicators were missing (U.S. Department of Education, 2000).

Procedure and Analytic Approach

Analyses were performed in R Version 3.6.1 (R Core Team, 2019) and *Mplus* Version 8 (Muthen & Muthen, 1998-2017). Fall kindergarten child-level weights (C1CW0) were applied to adjust for unequal probabilities of selection and nonresponse. The jackknife replication method was used to obtain design-adjusted standard errors and test statistics. Statistical significance was set at $\alpha = .05$.

Preliminary analysis. Multiple tests were performed to evaluate assumptions underlying the use of the traditional and RDD approaches. Covariate balance under the traditional DIF approach was evaluated in *Mplus* by performing bivariate group comparisons (English vs. Spanish form) on key demographic variables and the mathematics IRT theta scores, where standardized mean differences (SMDs) and odds ratios (ORs) were provided as measures of effect size.

Assumptions underlying the use of the RDD approach were tested as follows. First, frequency statistics disaggregated by group were calculated to determine whether an OLDS score of 37 was in fact a sharp cutpoint for assigning children to groups (i.e., English vs Spanish forms were correctly assigned based on the cutoff). Second, the assumption of local randomization—the existence of a window around the cutoff for which the design approximates a randomized experiment (Cattaneo et al., 2020)—was tested with the *rdlocrand* Version 0.5 package (Cattaneo, Titiunik, & Vazquez-Bare, 2019). Third, the *rdrobust* Version 0.99.4 package (Calonico, Cattaneo, Farrell, & Titiunik, 2018) was used to test balance on key demographic variables and the mathematics IRT theta scores at the OLDS proficiency cutpoint, with SMDs

and ORs provided as effect sizes. Fourth, a density discontinuity test, or McCrary test (McCrary, 2008), available via the *rddensity* Version 1.0 package in R (Cattaneo, Jansson, & Ma, 2019), was performed to test for discontinuity in the distribution of the OLDS scores at the cutpoint which could signify manipulation of the OLDS scores. Fifth, in conducting the DIF analyses, multiple bandwidths were considered to evaluate the sensitivity of the results.

RQ1: Investigation of DIF. A traditional evaluation of DIF was performed in *Mplus* by estimating a series of probit regression models:

$$\Phi^{-1}(\pi_{pc}) = \beta_{p0} + \beta_{p1}Ability_c + \beta_{p2}Group_c + \beta_{p3}Ability_cGroup_c \quad (1)$$

where Φ^{-1} is the inverse cumulative distribution function for the normal distribution (i.e., probit function), π_{pc} is the probability of a correct response to mathematics item p by child c , $Ability_c$ is the child's mathematics IRT theta score standardized so $M = 0$ and $SD = 1$ in the target subsample, and $Group_c$ is an indicator of the child's mathematics assessment language (0 = English, 1 = Spanish). Models were estimated via mean- and variance-adjusted weighted least squares (WLSMV). An item was flagged as demonstrating non-uniform DIF if a design-adjusted Wald test indicated that $\beta_{p3} \neq 0$. In the absence of non-uniform DIF, an item was flagged as demonstrating uniform DIF if a reduced model with $\beta_{p3} = 0$ indicated that $\beta_{p2} \neq 0$.

An RDD approach for evaluating DIF was also performed. The preferred method for RDD-based evaluations is non-parametric local polynomial regression. In order to carry out an investigation of non-uniform DIF, however, it was necessary to interact the covariate ($Ability_c$) with treatment ($Group_c$), which required parametric assumptions. Standard procedures for carrying out an RDD analysis were thus modified for this study. First, for each item, the *rdrobust* package in R was used to obtain empirically-derived bandwidths based on the following specifications: 1) Local linear regression; 2) $Ability_c$ as a covariate; 3) Triangular kernel

function; and 4) MSE-optimal bandwidth selector. Bandwidths 1 point smaller and 1 point bigger than the derived values were additionally obtained for sensitivity testing. Second, for each item, local linear probit regression using a triangular kernel weighting function and WLSMV estimation was performed in *Mplus*, where only cases with an OLDS score falling within the bandwidth were included in the analysis. Whereas the standard RDD approach for analyzing binary outcomes is the same for continuous outcomes, the inclusion of an interaction term in this study necessitated probit regression in order to adequately capture differences in slopes and avoid out-of-bounds predictions. Estimates of non-uniform and uniform DIF were obtained from the following model:

$$\begin{aligned}\Phi^{-1}(\pi_{pc}) = & \beta_{p0} + \beta_{p1}Ability_c + \beta_{p2}Group_c + \beta_{p3}Ability_cGroup_c + \beta_{p4}OLDS_c \\ & + \beta_{p5}Group_cOLDS_c\end{aligned}\quad (2)$$

where $OLDS_c$ is the OLDS score of the c^{th} child, centered at a cutpoint of 36.5 and with transformed standard deviation of 1; and the remaining terms are defined above. Because the OLDS is a discrete variable, assuming continuity at the cutpoint requires extrapolation for this study. Therefore, for all RDD analyses, we specified a cutpoint of 36.5 instead of 37 to minimize extrapolation on both sides of the cutpoint (cf., Robinson, 2010). The terms involving the assignment variable, β_{p4} and β_{p5} , are the usual terms in an RDD analysis that ensure the group effect is conditioned at the cutpoint. Due to interest in the $Ability_c$ by $Group_c$ interaction effect, higher-order terms $\beta_{p6}Ability_cOLDS_c$ and $\beta_{p7}Ability_cGroup_cOLDS_c$ were additionally considered for inclusion to ensure that β_{p3} was conditioned at the cutpoint. However, estimates were highly unstable with the addition of these terms, so they were not included in the final models.

Ordinary least squares standard errors from a local linear regression model based on an

MSE-optimal derived bandwidth selector are incorrect, with robust bias-corrected standard errors recommended as an alternative (Cattaneo et al., 2020). To obtain corrected standard errors, for each item, the model represented by Equation 2 was rerun using the same bandwidth but based on local quadratic probit regression via the addition of $\beta_{p6}OLDS_cOLDS_c$ and $\beta_{p7}Group_cOLDS_cOLDS_c$. The point estimates for non-uniform and uniform DIF were obtained from the local linear model, but 95% confidence intervals were obtained from the quadratic model (cf., Cattaneo et al., 2020).

For both DIF approaches, practical significance was assessed by estimating the signed and unsigned item difference in the sample (SIDS and UIDS, respectively; Meade, 2010). Because sampling weights are used in the current study to achieve estimates that are representative of the population, we instead refer to the effect sizes in terms of the population (SIDP, UIDP). The SIDP indicates the average difference in the expected item score across forms (English versus Spanish), holding constant mathematics ability, within the population represented by children who took the Spanish version. In the presence of non-uniform DIF, SIDP may be close to zero due to positive and negative differences canceling each other out. The UIDP represents the average *absolute value* of the difference in the expected item score across forms and thus provides a measure of expected item score difference assuming DIF uniformly favors one group. Because the items are dichotomous, SIDP has a possible range of -1 to 1 and UIDP has a possible range of 0 to 1. In calculating effect sizes for the RDD approach, the average expected score difference was conditionalized at the OLDS English proficiency cutpoint. This was achieved by obtaining the intercept of a local linear regression model with $OLDS_c$ as a predictor and the effect size measure as the outcome, where only cases with an OLDS score falling within the bandwidth were included in the analysis. To prevent out of bounds estimates,

UIDP scores were log transformed and then the resulting estimates were back transformed.

RQ2: Investigation of item bias. Following detection of significant DIF, item content was examined to evaluate the potential for DIF to be representative of item bias, as presence of DIF is not a sufficient condition to determine a given item is biased (Penfield & Lam, 2000). According to Penfield and Lam, to confirm that an item is biased one must be able to conclude that the differential performance across groups (or test forms) is due to a variable other than the underlying construct being assessed. However, to our knowledge there are no specific recommendations regarding procedures for examining item content to confirm bias. For this study, we evaluated whether specific item content for items displaying DIF revealed patterns that could explain presence of DIF. For example, we evaluated whether items included complex language that may influence student performance or whether item content included specific information (e.g., cultural references) irrelevant to the mathematics construct being assessed that may be unfamiliar to some children. If examination of item content revealed that differential performance of children across forms could be due to systematic reasons unrelated to underlying mathematics ability, we concluded that the items were biased.

Results

Preliminary Analysis

Traditional approach. Table 2 shows differences in key demographic variables and mathematics achievement across mathematics assessment language groups. Simple group comparisons (left-hand side) indicated no difference in gender or disability distribution, but children who were administered the English version were significantly more likely to be born in the U.S., be older, live in a household with higher SES, and have higher mathematics achievement than children who were administered the Spanish version.

[INSERT TABLE 2 ABOUT HERE]

RDD approach. Frequency distributions of OLDS scores by language group indicated a sharp cutoff at 36.5, with no children assigned to the Spanish form scoring above this cutoff, and no children assigned to the English form scoring below this cutoff. The assumption of local randomization was rejected, as covariate balance was not achieved within the smallest bandwidth ($h = .5, p = .038$ for SES). Accordingly, all subsequent RDD analyses were conducted under the continuity assumption. Table 2 (right-hand side) provides the tests of covariate balance at the OLDS cutoff. There were no statistically significant group differences in gender, country of birth, age, or mathematics scores. While also statistically non-significant, the magnitude of difference in disability distribution was sizeable ($OR = 6.40$), with children receiving the English version more likely to have a disability. In addition, children receiving the English version were significantly more likely to live in a household with higher SES. Figure 1 provides RD plots for the two demographic variables in question. The SES plot provides corroborating evidence, with clear visual discontinuity at the cutoff. The disability plot does not show clear discontinuity, in line with the statistically non-significant finding for this variable. Finally, the McCrary test was non-significant (robust $T = .07, p = .945$), suggesting no systematic unidirectional manipulation of OLDS scores at the cutpoint (see Figure 2 for the density discontinuity plot). Additional validity evidence of the RDD approach based on sensitivity of the results to different bandwidths is provided in the next section.

[INSERT FIGURE 1 ABOUT HERE]

[INSERT FIGURE 2 ABOUT HERE]

RQ1: Investigation of DIF

Traditional approach. Table 3 provides results for DIF under the traditional approach.

Seven items (25%) were flagged, all of which exhibited non-uniform DIF.² Figure 3 illustrates the predicted probability of a correct response by form language for these items. Holding mathematics achievement constant, items 1, 3, 4, 5, 24, and 25 were more discriminating (i.e., more strongly related to the underlying mathematics achievement construct) for the group that took the English version. Effect sizes were relatively small, ranging from UIDP = 0.03 (item 4) to 0.09 (item 3). In contrast, item 64 was more discriminating for the group that took the Spanish version (UIDP = 0.14).

[INSERT TABLE 3 ABOUT HERE]

[INSERT FIGURE 3 ABOUT HERE]

RDD approach. Table 4 provides results for DIF under the RDD approach. Based on the MSE-optimal bandwidth, three items (11%) were flagged, all of which exhibited uniform DIF. Figure 4 illustrates the predicted probability of a correct response by form language. Holding mathematics achievement constant, items 6, 28, and 29 were harder for the group that took the English form. Effect sizes ranged from UIDP = 0.01 (item 29) to 0.41 (item 6).

Results based on smaller and larger bandwidths (MSE-optimal bandwidth ± 1) are also presented in Table 4. Items 6 and 28 were also flagged for uniform DIF with the larger bandwidth but not the smaller bandwidth, whereas item 29 was also flagged for uniform DIF with the smaller bandwidth but not the larger bandwidth. Items 9 and 17 were additionally flagged for non-uniform DIF (less discriminating for English) with the larger bandwidth, and Item 5 was additionally flagged for uniform DIF (harder for English) with the smaller bandwidth. This indicated results were sensitive to the choice of bandwidth in the RDD analysis; however, magnitude of DIF effect sizes did not differ across bandwidths. It is also of note that

² Two of these items also exhibited uniform DIF, but we do not interpret the results because it would be akin to interpreting a main effect in the presence of a significant interaction effect.

for three of the seven items flagged for non-uniform DIF under the traditional approach, the estimate of the non-uniform parameter was the same or larger in magnitude under the RDD approach.

[INSERT TABLE 4 ABOUT HERE]

[INSERT FIGURE 4 ABOUT HERE]

RQ2: Investigation of Item Bias

Traditional approach. Among the seven items that were flagged for non-uniform DIF, three (items 1, 24, and 25) were Patterns, Algebra, and Functions items (comprising 75% of all Patterns, Algebra, and Functions items). These items required children to identify a pattern that matched a stimulus pattern. The language presented to the child was identical across all three of these items, and all items were multiple choice items (30% of all multiple-choice items) with four possible response options. This pattern of results may be related to differences in children across assessment forms (e.g., higher SES for English test takers); however, the overall small magnitude of effect size suggests any degree of bias is minimal³. The remaining four items exhibiting DIF were all Number Sense, Properties, and Operations items (21% of all Number Sense, Properties, and Operations items). All of these items were open ended responses (as was item 64, described below; 22% of all open-ended items). Of the three items for which performance was more strongly related to mathematics ability for the group that took the English test, two items (items 3 and 4) required children to identify the name of a displayed numeral and had identical stimulus language across items. The remaining item (item 5) required children to identify an object by its order in a sequence. The effect size for DIF was smaller for this item

³ Caution is warranted in interpreting results of scores on the Patterns, Algebra, and Functions items independently of the total score. Given that 75% of these items demonstrated DIF, it is possible that a subscale score derived from these items would be biased.

than for it was for some other items, although the estimated coefficient for DIF was larger than it was for other items. The item that was more related to math ability for the group that took the Spanish version (item 64) required children to count objects and credit for the item was given if they counted to a given number. No items were flagged as having DIF for other mathematics constructs (Measurement; Geometry and Spatial Sense; Data Analysis, Statistics, and Probability).

RDD approach. Among the three items that demonstrated uniform DIF (such that items were more difficult for the English form) when using the RDD approach, two (items 28 and 29) were Number Sense, Properties, and Operations items (11% of all Number Sense, Properties, and Operations items). These items required simple addition and subtraction operations and were open ended. The remaining item (item 6) that displayed DIF was a Measurement item (50% of all Measurement items). This item was a multiple-choice item for which children were shown an object and required to point to the one of four other objects that was shorter. No items were flagged as having DIF for other mathematics constructs (Patterns, Algebra, and Functions; Geometry and Spatial Sense; Data Analysis, Statistics, and Probability).

Discussion

The primary purposes of this study were to investigate DIF and item bias across Spanish and English forms of an assessment of early mathematics skills. Secondary purposes were to investigate the presence of selection bias and demonstrate a novel approach for investigating DIF that uses a regression discontinuity design framework to control for selection bias. Overall, there was minimal evidence of DIF and item/test bias across the Spanish and English forms of the ECLS-K kindergarten mathematics assessment. In contrast, there was significant evidence of selection bias, suggesting the need for a modified approach for evaluating DIF to account for

such bias. These findings have important implications for measurement of mathematics skills (and other academic skills) among DLLs and offer a new approach for evaluating the validity of assessment accommodations.

Evaluating Equivalence of Measurement across Test Forms

One standard approach employed to determine whether DLLs should be assessed in their native language or English is to administer an English language screening measure, and assign any children who score below a given cutoff on the measure to receive the assessment in their native language. Indeed, this is precisely the approach used by the ECLS-K study (U.S. Department of Education, 2000), for which we evaluated DIF in this study. In addition to the assumption that children have greater proficiency in their native language than in English, this approach assumes children receiving different language forms are otherwise similar and that the translations or adaptations of items across languages yield items that measure the same construct and are on the same scale. Thus, it is important to evaluate whether items function equivalently across forms while considering potential differences in test takers across forms. This framework guided our investigation of DIF on the ECLS-K kindergarten mathematics assessment.

Our results indicated that the groups of DLLs who received the English and Spanish forms differed on several important variables other than English language proficiency. Namely, groups differed on socioeconomic status, mathematics achievement, age, and whether they were born in the U.S. Evidence indicates that each of these variables is associated with language development, as DLLs whose mothers were born in the U.S. have greater English proficiency at kindergarten (Kim, Curby, & Winsler, 2014), children from higher SES homes often have stronger language skills (e.g., Hart & Risley, 1995), and there is a significant association between language skills and early numeracy, particularly for mathematics-related language

knowledge (Purpura & Reid, 2016; Toll & van Luit, 2014). Clear differences between groups on variables besides underlying mathematics achievement and the grouping mechanism of interest (i.e., form language) highlight the threat of selection bias in carrying out traditional investigations of DIF and item/test bias, which only control for differences in mathematics achievement. The modified RDD approach we employed resulted in improved covariate balance, but children still differed in SES across the English and Spanish forms of the assessment. Taken together, these findings highlight the limitations of both approaches, although the modified RDD approach appears to account for selection bias to a greater extent than does the traditional approach.

Consistent with our hypotheses, fewer items showed evidence of DIF when using the modified RDD approach (three items) than when using the traditional approach (seven items), and the nature of DIF also differed across approaches. Specifically, when using the traditional approach, most items with significant DIF exhibited non-uniform DIF such that they were more strongly related to the underlying math construct for the English form of the assessment than they were for the Spanish form of the assessment. In contrast, when using the RDD approach, all items exhibiting DIF exhibited uniform DIF such that they were more difficult for children who received the English form of the assessment. The latter finding suggests that Spanish-speaking DLLs who received the Spanish-language test accommodation may have had an unfair advantage over Spanish-speaking DLLs who were assigned to the English form of the assessment. However, because only three items (out of 28 items examined) demonstrated significant DIF when controlling for selection bias, we do not believe there is substantial bias in the overall mathematics scores derived from the two test forms. Therefore, the Spanish-language translation of the routing and low form of the ECLS-K kindergarten mathematics assessment appears to be a

valid assessment accommodation. This finding, in conjunction with the findings of Robinson (2010) that the accommodation was effective (students receiving the Spanish form scored higher than similar students who received the English form) provides support for the alternate-language assessment accommodation used in the ECLS-K study.

Implications for Assessment of Academic and Cognitive Skills among DLLs

Evaluations of DIF are a starting point for determining whether given items show evidence of bias in favor of one group over another (e.g., Hope, Adamson, McManus, Chis, & Elder, 2018). However, detection of bias requires more than presence of DIF, as there must be reason to suspect that extant DIF is due to systematic differences across groups of test takers on a variable unrelated to the construct being measured. Therefore, we examined item content to evaluate the potential for item bias.

Traditional approach to DIF. When using the traditional approach, examination of item content did not reveal consistent patterns that would be indicative of substantial item bias across forms. Although three of four items assessing children's pattern recognition skills exhibited DIF, the item wording was identical for the one item that did not exhibit DIF, and pattern stimuli (e.g., shapes, sizes) did not appear to differ in a way that could explain presence or lack of DIF. Prior evidence indicates that parents and preschool teachers engage in pattern-related activities frequently and speak with children about patterns they observe in the world on a regular basis (Rittle-Johnson, Fyfe, Loehr, & Miller, 2015). However, the frequency with which children are exposed to conversations about patterns in early home and school experiences may vary by socioeconomic status. Given that children who completed the English form of the assessment were more likely to come from high SES backgrounds, it is possible that differences in the association between performance on items assessing pattern knowledge and underlying

mathematics abilities across test forms are reflective of differences in SES rather than mathematics knowledge. However, it should be noted that SES is significantly correlated with early numeracy achievement (e.g., Anders et al., 2012). Given that our analysis controlled for mathematics achievement, differences across forms in SES are (at least partially) indirectly controlled as well, limiting the potential for item bias related to the form of the assessment itself.

As was the case for pattern items, the four Number Sense, Properties, and Operations items did not display a consistent pattern of item content to explain DIF. The items primarily involved counting or numeral identification, and several items that did not exhibit DIF also required counting or numeral identification, often with identical stimulus language to those items that exhibited DIF. Among the items displaying DIF, only one had questionable item content that could be plausibly tied to DIF. Specifically, item 5 references a water fountain. Notably, the Spanish instructions allow for multiple words to be used related to water fountain, *la fuente de agua* and *bebedero*. Thus, it is possible that variability in the language used for this item across examiners could result in item performance reflecting knowledge of the concepts described in the item rather than mathematics ability, representing potential bias. However, there were two other items on the assessment that permitted multiple Spanish words to be used to represent *banana*, and neither of these items exhibited DIF.

RDD approach. The measurement item that exhibited DIF required participants to point to an object that was shorter than a displayed target object. In contrast, the only other measurement item required children to identify how long a pictured object was (with a scale provided). The other two items that exhibited DIF when using the RDD approach required children to perform addition and subtraction, and did not appear to differ in content from similar items that did not show DIF.

Overall, examination of item content revealed little evidence of actual bias across both approaches. Notably, the items exhibiting DIF under the RDD approach were more difficult for children taking the English version of the assessment. Although we do not believe that our results show evidence of substantial item/test bias, a consistent pattern of higher difficulty of English items (after controlling for selection bias) would suggest that the cutoff used to assign forms may have been too low, disadvantaging children who performed just above the cutoff on the English language screener. Evidence indicates that young DLLs are a heterogeneous group regarding relative and absolute levels of proficiency in their first and second languages (Longian, Goodrich, & Farver, 2018). Given such heterogeneity, native language assessment accommodations may systematically underestimate some DLLs' true level of ability on the construct being assessed (e.g., mathematics), whereas it may allow other DLLs to demonstrate their true ability that would otherwise be masked by poor performance due to low English proficiency. Within the ECLS-K sample, there was a large correlation between Spanish and English language proficiency in the ECLS-K sample, indicating that children with lower English proficiency also had lower Spanish proficiency. Additionally, although Robinson (2010) found evidence of effectiveness of the Spanish-language accommodation in the ECLS-K sample, other recent research suggests that Spanish-language accommodations are not always effective (Abedi et al., 2020). Abedi et al. reported poorer performance on a mathematics assessment for students assigned to receive a Spanish-language form of the test and suggest that factors other than English proficiency (e.g., language of instruction) play a role in DLLs' assessment performance. Thus, decisions regarding alternate-language assessment accommodations need to carefully consider myriad factors such as proficiency in the home language and English, as well as whether instruction in the construct of interest has primarily occurred in children's home

language or in English.

Considerations for the Modified RDD Approach for Examining DIF

Our analysis highlighted several limitations of the modified RDD approach in this context. First, results were sensitive to the choice of bandwidth in the RDD analysis. Three additional items were identified as exhibiting DIF, and items identified as exhibiting DIF using the data-driven bandwidth sometimes did not exhibit DIF when a smaller or larger bandwidth was used. This could be problematic for interpretation of the RDD approach; however, the magnitude of DIF estimates and associated effect sizes did not differ substantially across different bandwidths.

Second, results of the RDD analysis revealed potential issues related to statistical power when using this approach. Non-parametric local linear regression uses only a subset of cases that are close to the cut-off to reduce bias in the estimate of the average treatment effect. Thus, even if the total sample size is large the effective sample size (the number of cases used in the regression) may not be large. Although the total sample size exceeded 1600 for all items, the effective sample size was less than 700 for all items and less than 500 for approximately two-thirds of the items. For several items flagged as having non-uniform DIF when using the traditional approach but not when using the RDD approach (e.g. items 1 and 24), DIF effect size estimates were larger in the RDD approach. Similarly, discrepancies in the magnitude of effect size and corresponding effect sizes emerged across items within the RDD approach. For example, item 29 was flagged as exhibiting uniform DIF with a SIDP value of $-.04$. Other items with comparable or larger sample sizes were not flagged as exhibiting uniform DIF despite having substantially greater effect sizes (e.g., item 33). Effect size estimates generated from the RDD approach should be interpreted with caution, as these effect size indices were not

developed for use with an RDD approach to evaluating DIF. Taken together, issues related to apparent lack of statistical power and inconsistencies in the correspondence between statistical significance and effect size suggest a need for caution when interpreting these findings.

Limitations

Although the results of this study have the potential to advance knowledge regarding measurement of academic skills among DLLs, this study has some limitations. First, this dataset is old, as it represents the 1998-1999 cohort of ECLS-K. Unfortunately, item-level data are not available for the newer kindergarten cohort. However, the extent to which this is a noteworthy limitation is mitigated by the fact that items for mathematics assessments have not changed substantially in the last 20 years, and the mathematics test used in the ECLS-K 2011 cohort was based on the mathematics framework used for the 1996 National Assessment of Educational Progress. Relatedly, limitations in information describing the sample limit our ability to examine how heterogeneity within the analytic sample influences the results. For example, it is possible that dialectical differences in Spanish used by children from different countries yield different patterns of item/test bias. However, there is no information about Spanish dialect spoken by children in the ECLS-K dataset, and the only information on country of origin is for children who were not born in the U.S. (approximately 12% of our sample). Therefore, we could not evaluate whether the validity of the Spanish-adapted items varied across dialect or country of origin. Finally, although our novel RDD approach for controlling selection bias in evaluations of DIF showed promise when compared to traditional evaluations of DIF, there were many methodological limitations to this approach that warrant additional research. These limitations include: reliance on parametric assumptions to investigate non-uniform DIF; use of empirically-derived bandwidth selectors and robust confidence intervals that were not developed with the

purpose of testing interactions or for use with categorical data; use of DIF effect sizes that have not been studied for use within an RDD framework; and omission of potentially important higher-order terms in the RDD model due to instability in the parameter estimates.

Conclusions

Overall, the results of this study demonstrated little evidence of item or test bias on the ECLS-K kindergarten mathematics assessment, providing evidence that the Spanish-language form is a valid assessment accommodation for DLLs. Moreover, we observed that children assigned to different assessment forms differed on characteristics other than underlying mathematics achievement and language form/English proficiency. This introduces selection bias that needs to be controlled when evaluating DIF and subsequently making inferences about item/test bias. Although our approach was not without its own limitations, it reduced the selection bias present and led to different and potentially more accurate conclusions regarding DIF and item/test bias on a mathematics assessment. Ensuring accurate and fair assessment for all children is a core tenet of the Every Student Succeeds Act (2016). Therefore, additional research is needed to develop and validate methodological techniques for ensuring fair assessment approaches.

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Table 1

*Unweighted Descriptive Statistics of Kindergarten Mathematics Items
Based on the Subsample of Children With a Home Language of Spanish*

Item	Content	Format	n	Prop. Correct	$r_{PB}(\text{item, theta})$
1	PAF	MC	1720	.44	.28
2	NSPO	OE	1750	.27	.59
3	NSPO	OE	1750	.43	.69
4	NSPO	OE	1750	.13	.49
5	NSPO	OE	1750	.10	.41
6	MEAS	MC	1740	.47	.35
7	NSPO	OE	1750	.16	.39
9	NSPO	OE	1750	.19	.36
10	NSPO	MC	1700	.18	.16
17	NSPO	OE	1670	.96	.29
18	NSPO	MC	1650	.82	.36
19	NSPO	OE	1670	.34	.42
20	NSPO	OE	1670	.73	.71
21	NSPO	OE	1670	.55	.68
22	NSPO	OE	1740	.18	.52
23	GSS	MC	1660	.83	.33
24	PAF	MC	1710	.49	.32
25	PAF	MC	1680	.41	.27
26	PAF	MC	1680	.40	.22
27	NSPO	OE	1750	.19	.27
28	NSPO	OE	1740	.51	.33
29	NSPO	OE	1750	.05	.27
30	NSPO	OE	1740	.16	.20
31	MEAS	MC	1690	.54	.40
32	DSP	OE	1750	.47	.50
33	DSP	OE	1740	.56	.43
34	NSPO	MC	1700	.34	.24
64	NSPO	OE	1750	.76	.52

Note. Sample sizes rounded to the nearest ten. Prop. = proportion.

$r_{PB}(\text{item, theta})$ = point-biserial correlation between the item and overall mathematics IRT theta score. PAF = patterns, algebra, functions. NSPO = number sense, properties, operations. MEAS = measurement. GSS = geometry, spatial sense. DSP = data analysis, statistics, probability. MC = multiple choice. OE = open-ended.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Student Assessment,” fall 1998.

Table 2

Comparison of Kindergarten Demographic Variables and Mathematics Achievement Across Mathematics Assessment Language Groups

Variable	Simple Group Difference (English Form - Spanish Form)					Group Difference at the English Proficiency Cutpoint (English Form - Spanish Form)				
	n	Est.	SE	p	Effect Size	n	Est.	SE	p	Effect Size
Female	1750	0.02 ^a (0.01 ^b)	0.07 ^a	.786	OR = 1.03	550	-0.13 ^b	0.16 ^b	.406	OR = 0.59
Disability	1540	0.03 ^a (0.00 ^b)	0.13 ^a	.833	OR = 1.06	50	0.05 ^b	0.05 ^b	.197	OR = 6.40
U.S. born	1510	0.53 ^a (0.10 ^b)	0.09 ^a	< .001	OR = 2.79	540	0.07 ^b	0.08 ^b	.196	OR = 2.12
Age in months	1750	1.00	0.26	< .001	SMD = 0.23	390	0.44	1.39	.680	SMD = 0.10
Household SES	1640	0.46	0.04	< .001	SMD = 0.75	300	0.39	0.27	.032	SMD = 0.63
Mathematics IRT score	1750	0.67	0.07	< .001	SMD = 0.67	390	0.18	0.30	.317	SMD = 0.18

Note. Sample sizes rounded to the nearest ten. OR = Odds ratio. SMD = Standardized mean difference. ^aProbit scale. ^bProbability scale.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Parent-Guardian Interview,” fall 1998 and spring 1999, “Student Assessment,” fall 1998.

Table 3

Estimated DIF Parameters and Effect Sizes Under the Traditional Approach

Item	Non-Uniform		Uniform		SIDP	UIDP
	Est.	95% CI	Est.	95% CI		
1	0.18*	(0.05, 0.30)	0.08	(-0.05, 0.21)	0.01	0.05
2	-0.23	(-0.55, 0.10)	0.12	(-0.05, 0.29)	0.03	0.03
3	0.42*	(0.06, 0.79)	-0.43*	(-0.58, -0.28)	-0.08	0.09
4	0.46*	(0.13, 0.79)	0.16	(-0.03, 0.35)	0.01	0.03
5	0.87*	(0.60, 1.14)	0.09	(-0.11, 0.28)	0.00	0.04
6	0.09	(-0.06, 0.24)	-0.04	(-0.15, 0.07)	-0.02	0.03
7	0.08	(-0.16, 0.32)	-0.11	(-0.30, 0.07)	-0.02	0.02
9	0.04	(-0.14, 0.23)	0.10	(-0.09, 0.28)	0.02	0.02
10	0.10	(-0.09, 0.28)	-0.14	(-0.29, 0.02)	-0.04	0.04
17	-0.03	(-0.60, 0.54)	0.05	(-0.26, 0.36)	0.00	0.00
18	-0.16	(-0.40, 0.08)	0.12	(-0.03, 0.28)	0.05	0.05
19	0.05	(-0.13, 0.24)	0.02	(-0.12, 0.15)	0.00	0.01
20	0.25	(-0.25, 0.76)	0.08	(-0.17, 0.33)	0.01	0.01
21	0.14	(-0.17, 0.46)	-0.06	(-0.22, 0.11)	-0.02	0.02
22	0.08	(-0.18, 0.34)	0.03	(-0.16, 0.22)	0.00	0.01
23	0.15	(-0.08, 0.37)	0.07	(-0.13, 0.27)	0.00	0.02
24	0.19*	(0.04, 0.34)	0.08	(-0.10, 0.27)	0.01	0.05
25	0.21*	(0.07, 0.34)	0.04	(-0.12, 0.20)	-0.01	0.05
26	0.03	(-0.11, 0.16)	-0.05	(-0.20, 0.09)	-0.02	0.02
27	0.06	(-0.16, 0.28)	-0.03	(-0.21, 0.15)	-0.01	0.01
28	0.03	(-0.12, 0.18)	0.03	(-0.10, 0.15)	0.01	0.01
29	0.24	(-0.06, 0.55)	-0.07	(-0.32, 0.18)	-0.01	0.01
30	0.19	(-0.03, 0.41)	-0.12	(-0.27, 0.03)	-0.04	0.04
31	0.04	(-0.14, 0.22)	-0.10	(-0.26, 0.06)	-0.04	0.04
32	-0.08	(-0.26, 0.10)	0.02	(-0.14, 0.18)	0.01	0.02
33	-0.01	(-0.17, 0.14)	0.00	(-0.17, 0.16)	0.00	0.00
34	0.17	(-0.02, 0.36)	-0.12	(-0.26, 0.03)	-0.05	0.06
64	-0.34*	(-0.62, -0.07)	0.45*	(0.24, 0.65)	0.14	0.14

Note. Sample sizes are provided in Table 1. The Spanish group is the reference group. Uniform DIF estimates are based on reduced model with non-uniform DIF parameter fixed at 0. SIDP = signed item difference (English - Spanish) in the population for the focal (Spanish) group. UIDP = unsigned item difference (English - Spanish) in the population for the focal (Spanish) group.

* $p < .05$

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Student Assessment,” fall 1998.

Table 4

Estimated DIF Parameters and Effect Sizes Under the RDD Approach

Item	n	h	Non-Uniform		Uniform		SIDP	UIDP
			Est.	95% CI	Est.	95% CI		
1	380	6.24	-0.05	(-0.40, 0.31)	-0.28	(-1.02, 1.09)	-0.11	0.11
1	450	7.24	-0.04	(-0.37, 0.30)	-0.27	(-0.93, 0.60)	-0.10	0.10
1	540	8.24	-0.02	(-0.32, 0.28)	-0.23	(-0.88, 0.37)	-0.09	0.11
2	550	7.77	-0.42	(-1.16, 0.32)	0.17	(-0.80, 1.24)	0.03	0.02
2	590	8.77	-0.41	(-1.11, 0.29)	0.17	(-0.70, 1.12)	0.03	0.02
2	640	9.77	-0.42	(-1.08, 0.26)	0.17	(-0.71, 1.12)	0.03	0.02
3	260	4.45	-0.11	(-1.09, 0.92)	0.49	(-1.86, 1.94)	0.09	0.01
3	320	5.45	-0.13	(-1.11, 0.85)	0.47	(-0.85, 1.60)	0.09	0.01
3	390	6.45	-0.06	(-1.01, 0.87)	0.40	(-0.66, 1.72)	0.07	0.01
4	550	7.64	0.95	(-0.41, 2.30)	0.03	(-1.51, 1.21)	0.01	0.02
4	590	8.64	0.88	(-0.32, 2.06)	0.04	(-1.11, 0.89)	0.02	0.02
4	640	9.64	0.82	(-0.17, 1.81)	0.05	(-1.00, 0.87)	0.02	0.02
5	390	5.68	1.27	(-0.21, 2.74)	-1.02*	(-3.60, -0.14)	-0.05	0.03
5	460	6.68	1.11	(-0.14, 2.32)	-0.97	(-3.92, 0.88)	-0.05	0.03
5	550	7.68	0.99	(-0.08, 2.04)	-1.04	(-2.58, 0.13)	-0.05	0.03
6	320	5.19	0.01	(-0.32, 0.33)	-0.85	(-1.52, 0.13)	-0.31	0.34
6	390	6.19	0.00	(-0.32, 0.33)	-0.82*	(-1.53, -0.05)	-0.30	0.41
6	460	7.19	0.00	(-0.29, 0.29)	-0.79*	(-1.53, -0.19)	-0.29	0.38
7	260	3.70	0.19	(-0.74, 1.09)	-0.87	(-2.76, 0.45)	-0.10	0.09
7	320	4.70	0.14	(-0.61, 0.89)	-0.79	(-2.55, 0.27)	-0.09	0.08
7	390	5.70	0.15	(-0.53, 0.84)	-0.71	(-2.42, 0.24)	-0.09	0.07
9	390	5.54	-1.04	(-2.46, 0.21)	-0.29	(-2.52, 0.63)	-0.04	0.03
9	460	6.54	-1.01	(-2.42, 0.10)	-0.24	(-2.36, 0.94)	-0.04	0.03
9	550	7.54	-0.93*	(-1.76, -0.25)	-0.23	(-1.70, 0.76)	-0.04	0.03
10	380	5.55	-0.13	(-0.65, 0.39)	-0.29	(-1.95, 1.16)	-0.04	0.05
10	450	6.55	-0.11	(-0.59, 0.37)	-0.20	(-1.81, 0.88)	-0.03	0.04
10	540	7.55	-0.08	(-0.52, 0.38)	-0.15	(-1.75, 0.87)	-0.02	0.03
17	380	5.90	-1.45	(-5.43, 2.34)	-1.37	(-3.84, 0.24)	-0.06	0.00
17	450	6.90	-1.34	(-3.05, 0.44)	-0.91	(-3.86, 0.53)	-0.04	0.01
17	530	7.90	-1.14*	(-2.19, -0.12)	-0.70	(-3.50, 0.79)	-0.03	0.01
18	380	6.06	0.51	(-0.13, 1.14)	0.50	(-0.67, 1.45)	0.10	0.11
18	440	7.06	0.44	(-0.13, 1.02)	0.47	(-0.40, 1.36)	0.09	0.10
18	530	8.06	0.38	(-0.14, 0.90)	0.42	(-0.29, 1.38)	0.08	0.08
19	530	8.00	-0.02	(-0.48, 0.44)	0.03	(-1.74, 1.49)	0.01	0.03
19	570	9.00	-0.01	(-0.43, 0.40)	0.03	(-1.15, 0.95)	0.02	0.03
19	620	10.00	-0.01	(-0.42, 0.39)	0.04	(-1.03, 0.91)	0.02	0.03
20	620	9.59	-0.15	(-1.57, 1.33)	0.55	(-0.50, 1.78)	0.07	0.01
20	670	10.59	-0.11	(-1.31, 1.11)	0.53	(-0.37, 1.67)	0.07	0.01
20	720	11.59	-0.04	(-1.19, 1.10)	0.52	(-0.45, 1.67)	0.07	0.01
21	320	5.41	-0.34	(-1.21, 0.54)	-0.15	(-2.10, 0.84)	-0.02	0.01
21	380	6.41	-0.13	(-0.98, 0.58)	0.00	(-1.79, 0.57)	-0.00	0.00
21	450	7.41	-0.04	(-0.78, 0.60)	-0.01	(-1.26, 0.70)	-0.00	0.00

22	390	6.28	0.29	(-0.62, 1.21)	0.83	(-2.24, 3.89)	0.14	0.06
22	460	7.28	0.35	(-0.48, 1.19)	0.78	(-0.81, 2.64)	0.14	0.05
22	550	8.28	0.41	(-0.38, 1.22)	0.69	(-0.35, 2.39)	0.12	0.04
23	450	6.81	0.06	(-0.35, 0.52)	-0.18	(-2.72, 1.57)	-0.05	0.03
23	530	7.81	0.04	(-0.34, 0.46)	-0.12	(-2.34, 1.40)	-0.03	0.01
23	570	8.81	0.02	(-0.33, 0.40)	-0.09	(-1.92, 1.13)	-0.02	0.00
24	320	5.08	0.05	(-0.31, 0.41)	0.60	(-0.12, 1.82)	0.22	0.10
24	380	6.08	0.08	(-0.25, 0.41)	0.55	(-0.05, 1.67)	0.20	0.08
24	450	7.08	0.09	(-0.21, 0.40)	0.50	(-0.08, 1.56)	0.18	0.09
25	370	5.56	0.22	(-0.16, 0.60)	-0.12	(-0.80, 1.06)	-0.04	0.05
25	440	6.56	0.21	(-0.15, 0.56)	-0.16	(-0.84, 0.94)	-0.06	0.05
25	530	7.56	0.17	(-0.14, 0.47)	-0.16	(-0.89, 0.78)	-0.06	0.05
26	370	5.80	-0.10	(-0.44, 0.26)	0.31	(-1.02, 1.39)	0.12	0.04
26	440	6.80	-0.10	(-0.42, 0.24)	0.31	(-0.98, 1.51)	0.11	0.04
26	530	7.80	-0.10	(-0.41, 0.22)	0.25	(-0.61, 1.35)	0.09	0.04
27	260	4.12	-0.22	(-0.76, 0.32)	0.67	(-0.45, 2.14)	0.16	0.17
27	320	5.12	-0.17	(-0.67, 0.33)	0.64	(-0.54, 2.08)	0.15	0.16
27	390	6.12	-0.13	(-0.59, 0.32)	0.55	(-0.22, 1.89)	0.13	0.13
28	320	5.46	-0.15	(-0.56, 0.25)	-0.98	(-2.41, 0.77)	-0.36	0.36
28	380	6.46	-0.16	(-0.50, 0.19)	-0.88*	(-2.02, -0.05)	-0.32	0.33
28	460	7.46	-0.16	(-0.49, 0.16)	-0.84*	(-1.84, -0.22)	-0.31	0.31
29	390	5.93	0.14	(-0.93, 0.94)	-0.49*	(-3.06, -0.60)	-0.05	0.01
29	460	6.93	0.10	(-0.87, 0.88)	-0.49*	(-2.06, -0.05)	-0.04	0.01
29	550	7.93	0.06	(-0.78, 0.74)	-0.57	(-2.15, 0.61)	-0.04	0.01
30	320	5.50	0.16	(-0.43, 0.70)	0.34	(-1.90, 3.41)	0.07	0.02
30	380	6.50	0.11	(-0.38, 0.63)	0.39	(-0.73, 1.70)	0.08	0.04
30	460	7.50	0.08	(-0.37, 0.55)	0.35	(-0.42, 1.36)	0.08	0.06
31	540	8.01	-0.06	(-0.47, 0.35)	0.00	(-0.61, 0.69)	-0.00	0.01
31	580	9.01	-0.05	(-0.42, 0.32)	-0.03	(-0.61, 0.76)	-0.01	0.01
31	630	10.01	-0.05	(-0.41, 0.31)	-0.05	(-0.67, 0.82)	-0.02	0.01
32	320	5.43	0.19	(-0.18, 0.57)	0.27	(-0.40, 1.26)	0.09	0.07
32	390	6.43	0.19	(-0.17, 0.55)	0.16	(-0.57, 1.57)	0.05	0.04
32	460	7.43	0.19	(-0.16, 0.52)	0.11	(-0.64, 1.44)	0.04	0.04
33	590	9.15	0.18	(-0.17, 0.52)	-0.33	(-1.84, 1.76)	-0.12	0.13
33	640	10.15	0.19	(-0.15, 0.52)	-0.34	(-1.40, 1.15)	-0.13	0.13
33	690	11.15	0.19	(-0.13, 0.52)	-0.35	(-1.20, 0.80)	-0.13	0.12
34	440	6.77	0.19	(-0.22, 0.60)	0.22	(-1.05, 1.69)	0.06	0.03
34	530	7.77	0.23	(-0.15, 0.59)	0.26	(-0.76, 1.20)	0.07	0.03
34	570	8.77	0.26	(-0.06, 0.56)	0.28	(-0.74, 1.17)	0.08	0.04
64	550	8.45	-0.35	(-0.97, 0.26)	0.20	(-0.89, 0.96)	0.06	0.03
64	590	9.45	-0.33	(-0.88, 0.21)	0.22	(-0.78, 0.89)	0.06	0.03
64	640	10.45	-0.33	(-0.77, 0.10)	0.27	(-0.75, 0.80)	0.08	0.04

Note. Sample sizes rounded to the nearest 10. The Spanish group is the reference group. Uniform DIF estimates are based on reduced model with non-uniform DIF parameter fixed at 0. h = bandwidth. Shaded (middle) row for each item indicates data-driven bandwidth. First and third row for each item (± 1 data-driven bandwidth) included for

sensitivity testing. SIDP = signed item difference (English - Spanish) in the population for the focal (Spanish) group. UIDP = unsigned item difference (English - Spanish) in the population for the focal (Spanish) group.

* $p < .05$

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Student Assessment,” fall 1998.

Figure 1. RD plot for household SES composite score and child disability status. Cutpoint = 36.5. $n = 1640$ for SES and $n = 1540$ for disability (sample sizes rounded to the nearest ten). Shaded regions indicate 95% confidence intervals.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Parent-Guardian Interview,” fall 1998 and spring 1999, “Student Assessment,” fall 1998.

Figure 2. Density discontinuity plot of OLDS scores. $n = 1750$ (sample size rounded to the nearest 10). Cutpoint = 36.5. Shaded regions indicate 95% confidence intervals. The McCrary test was non-significant, failing to provide evidence of discontinuity at the OLDS cutpoint (robust $T = .07$, $p = .945$ based on a local quadratic polynomial with a triangular kernel function, MSE-optimal bandwidth selector with $h = 7.94$ [below cutoff] and $h = 6.14$ [above cutoff], and effective $n = 430$).

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Student Assessment,” fall 1998.

Figure 2. Predicted probability of a correct response by mathematics assessment language group for items flagged for DIF under the traditional method. Sample sizes are provided in Table 1.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Student Assessment,” fall 1998.

Figure 3. Predicted probability of a correct response by mathematics assessment language group for items flagged for DIF under the RDD method. Sample sizes are provided in Table 4.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), “Student Assessment,” fall 1998.