ALGEBRA ACHIEVEMENT GAPS: A COMPARATIVE STUDY ACROSS THE STATES OVER THE YEARS

Rachel A. Ayieko
Duquesne University
ayiekor@duq.edu

Elif N. Gokbel
Duquesne University
karalie@duq.edu

Ahmet O. Akcay
Duquesne University
akcaya@duq.edu

The purpose of this study was to examine eighth grade students' algebra achievement scores across various states, over years, and by students' demographics (including ethnicity/race, language spoken at home, SES factors, and academic resources). The questions guiding the study were, (a) What are the differences in eighth grade students' algebra achievement scores across sixteen states between the years 2005 to 2015? (b) Are there significant differences in eighth grade students' algebra achievement scores by student demographics? There were significant differences found in the students' algebra achievement scores based on different students' demographics. Further, the students' mean algebra scale scores continue to rise over the years.

Keywords: Algebra and Algebraic Thinking, Equity and Diversity, Policy Matters, and Middle School Education

Introduction

The move towards "Algebra for All" is based on the notion that success in Science, Technology, Engineering, and Mathematics (STEM) competencies in the 21st century requires fluency in algebraic reasoning and problem solving. Although there is a great need for more students to join the STEM fields, few students pursue these fields in higher education. Scholars have proposed that algebraic thinking should be introduced in the early grades to ease the transition to learning complex algebra (e.g., Blanton & Kaput, 2011; Cai & Knuth, 2011). Indeed, research has shown that it is possible for students in the earlier grades to engage in functional thinking (Warren, Cooper, & Lamb, 2006), and algebraic reasoning (Bjuland, 2012).

The motivation of this study, therefore, is to examine the algebra achievement of eighth- grade students in various states. This comparative study will illuminate the algebra knowledge that students enter high school with as they begin the algebra requirement or their development of early algebraic thinking. Further, it will also illustrate the improvements in early algebra learning over the years. The algebra strand of mathematics is important because of the varying content taught across and within the United States (Kieran, 2007). More importantly, the abstract nature of algebraic reasoning, the language of mathematics using symbols, and structural characteristics associated with learning algebra makes it a challenging strand of mathematics (Rakes, Valentine, McGatha, & Ronau, 2010). Further, considering the adoption of the Common Core State Standards (2010) across the United States, there is the need to examine the influence of this initiative in the algebra achievement of students before they join high school.

The questions guiding this study are, (a) What are the differences in eighth-grade students' algebra achievement scores across sixteen states between the years 2005 to 2015? (b) Are there significant differences in eighth-grade students' algebra achievement scores by ethnicity/race, language spoken at home, socio-economic status (SES) factors, and academic resources? This report contains information on algebra achievement across various states, over the years, and by students' backgrounds. To compare students' algebra scores, we selected states identified as benchmark states in previous cross-national studies (e.g. Trends in Mathematics and Science Studies-2011) and the ten states with available data in the High School Longitudinal Study (HSLS). Using the National Assessment of Educational Progress (NAEP) data from 2005 to 2015, we present the trends in students' achievement in sixteen states.

Wood, M. B., Turner, E. E., Civil, M., & Eli, J. A. (Eds.). (2016). *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Tucson, AZ: The University of Arizona.

The findings from this study will be used to inform the next series of studies that will investigate the opportunities to learn algebra related to the differential algebra achievements across the United States. Further, the states in which students' algebra achievement is higher based on students' demographics, and the states that have narrower algebra achievement gaps provide information for policy and practice.

Theoretical Framework

Overall, students' mathematics achievement in the United States has shown a steady improvement over the years in the different grade levels (e.g., Hemphill & Vanneman, 2011; Vanneman, Hamilton, Baldwin Anderson, & Rahman, 2009). However, the variation in mathematics achievement across different groups of students across the United States is prevalent. The studies that focus on mathematics achievement gaps include those that examine gaps across races, socioeconomic status, gender, and factors explaining the gaps that are predominant (e.g., Lubienski, Robinson, Crane & Ganley, 2013; McGraw, Lubienski, & Strutchens, 2006; Lubienski, 2002). Lubienski's (2008) research commentary emphasized the need for more mathematics educators to focus on gap analysis to inform education policy, classroom practices, and research. Additionally, the commentary points to the need to focus on opportunity gaps related to the inequities found in mathematics achievement (Lubienski, 2008). Furthermore, gap analyses inform public opinions and deficit notions when carefully conducted using factors related to the disparities found (Lubienski, 2008). Some suggestions for useful analysis suggested in the commentary include the study of gaps found in different strands of mathematics, intersections of race and socioeconomic status that could include or exclude gender. The literature cited in the present study includes achievements gaps by race, socioeconomic status, and language spoken at home. However, the information from the studies shown is in general mathematics without providing knowledge of particular strands of mathematics.

Racial and Socioeconomic Differences in Mathematics Achievement

Mathematics achievement gaps between races and socioeconomic status have abounded over the years. A study done by Lubienski (2002) that examined achievement gaps by race and socioeconomic status indicated that there were significant achievement gaps by race among students from both high SES and low SES backgrounds. In particular, white students with the lowest SES scored significantly higher or at par when compared to the black students in the highest SES in fourth, eighth and twelfth grade in 1990 and 1996. These findings indicate that racial achievement differences cannot be assumed to be the same as the socioeconomic differences. Indeed, the white students considered as low socioeconomically perform higher than black students from low socioeconomic backgrounds. Similarly, a focus on the SES across races, considering the socioeconomic measure on eligibility for free and reduced lunch, showed that in the fourth and eighth grade, the achievement gaps persisted by race. Specifically, for the fourth- grade students there was a significant achievement gap between those that received reduced price lunch in 2004 and 2007 for the black/white comparison. Further, among the eighth-grade students there were narrower achievement gaps in 2007 for free and reduced lunch, indicating that in this SES level, there was an improvement gain in the black students' mathematics achievement (Vanneman et al., 2009).

A focus on the achievement differences in Hispanics and White students also shows that the achievement gaps are narrowing. In particular, between 1990 and 2009 there was an improvement in Hispanics mathematics achievement. However, across these two years the difference in the achievement gaps was not significant (Hemphill & Vanneman, 2011).

The patterns of achievement gaps in mathematics are not consistent across the United States. Although there was a steady gain in eighth-grade mathematics achievement scores over the years in 41 states, the achievement gaps in Arkansas, Texas, Colorado, and Oklahoma was smaller in 2007, when compared to the gap in 1990. Similarly, the gaps between the black and white students in the

Wood, M. B., Turner, E. E., Civil, M., & Eli, J. A. (Eds.). (2016). *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Tucson, AZ: The University of Arizona.

fourth grade were narrower in 2007 than in 1990 in 46 states (Vanneman, et al., 2009). In sum, these findings show that the persistence of these achievement gaps across the grade levels indicate that there could be other factors contributing to these gaps.

Differences in Mathematics Achievement by Language Spoken at Home

Students' language background is related to mathematics achievement. Howie's (2005) study indicated that students who spoke the language of the test (e.g. English) more frequently at home had higher scores on the mathematics test. Additionally, white pupils' mathematics scores were significantly higher than other groups who are not speaking English at home (Howie, 2005). Likewise, Reardon and Galindo (2008) found that fifth-grade students from homes where English is not the predominant language scored lower than students from English-speaking homes. These earlier studies show that there is need to analyze further the mathematics achievement gap comparing students' who use other languages other than English at home and those who do not are changing over the years and across states. In so doing, the results could indicate that the interventions on English language acquisition are influencing mathematics achievement.

Algebra achievement

The algebra content of mathematics is a gatekeeper in the selection of further mathematics and future career of students (Kaput, 2000). Some studies have shown that differences in the algebra achievement are too often associated with demographic and personality variables of students such as ethnicity, socioeconomic status, teacher quality, and student attitudes (e.g., McCoy, 2005) and instructional strategies (e.g., Rakes et al., 2010). Spielhagen (2006) suggested that the reduction of the opportunity gap and improved achievement is possible with the introduction of more algebra courses in the earlier grades. Similarly, other scholars have suggested that learning algebra in the early grades provides a strong baseline for more complex algebraic thinking that students experience in high school and beyond (e.g., Blanton & Kaput, 2011; Carraher & Schliemann, 2007).

In sum, these findings show that the persistence of these achievement gaps across the grade levels suggest that factors contributing to this scenario. One of the factors could be the algebra knowledge that students have acquired before joining secondary school. The level of algebra knowledge which can be either an advantage for learning further algebra content or not succeeding or selecting higher-level algebra-related courses.

Methods

The NAEP Main Assessment

The National Assessment of Educational Progress (NAEP) data provides information across the United States and over the years for possible state-level comparisons. The state assessments of NAEP have been administered across the states in grades 4, 8, and 12 in various subject matters since 1990. This data provides representative samples of students' mathematics achievement in grades four and eight from each state every two years. For example, 136,900 eighth grade students took the assessment throughout the nation in 2015. The NAEP assessment items include a variety of formats, such as multiple-choice and open-ended questions (requiring short constructed-response, and extended-response). The test items were classified by mathematical complexity: low complexity, moderate complexity, and high complexity. Each assessment question was designed to measure one of the five mathematics strands: number properties and operations, measurement, geometry, data analysis/statistics, and algebra. The data used in this study were from the years between 2005-2015 main NAEP mathematics assessments, and the participants that were the focus of this study were the eighth-grade students.

Wood, M. B., Turner, E. E., Civil, M., & Eli, J. A. (Eds.). (2016). *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Tucson, AZ: The University of Arizona.

Variables

The NAEP background questionnaire items that were selected for this analysis include: language other than English spoken at home, student-reported mother's education level, the number of books at home, lunch eligibility, and race/ethnicity. Specifically, a description of the independent variables including the categories are: (a) A language other than English spoken at home (never (1), one in a while (2), half of the time (3), and all or most of the time (4); (b) Lunch eligibility (not eligible, reduced price lunch, and free lunch); (c) Academic resources including Mother's education level (did not finish high school, graduated college) and Books at home (less than 10 books, more than 100 books), For the academic resources at home the highest and lowest ordered responses were used; and (d) Race/ethnicity allowing multiple responses (White, Black, and Hispanic).

Analysis

Descriptive statistics were run using the NAEP Data Explorer (NDE) tool to illustrate the gap in eighth-grade students' average algebra scores across contexts, races and SES in selected states and over the years. The NDE is an online data analysis program that provides detailed results' from NAEP's national and state assessments. An independent-samples *t*-test was conducted to analyze differences between average algebra scores of eighth-grade students (a) whose mothers did not finish high school and those whose mothers graduated from college, and (b) who have less than 10 books at home and those having more than 100 books at home. An analysis of variance (ANOVA) was conducted to examine how the average algebra scores differ among (a) three ethnicity groups, (b) lunch eligibility (including "not eligible, reduced price lunch and free lunch"), academic resources and (c) language other than English spoken at home. Other ANOVA tests were also performed to assess the differences in algebra scores by ethnicity, lunch eligibility, academic resources, and a language other than English spoken at home over the years from 2005 to 2015.

Results

The results of this study were from nationally representative samples of eighth grade students from public and private schools. The alpha level (.05) for the quantitative analyses indicated that there was a statistically significant difference between the independent variables. Due to space limitations, for descriptive statistics we only provide Figure 1 presenting average algebra scale scores for eighth graders by ethnicity.

Race/Ethnicity

Figure 1 presents the graphs of the average algebra scores of the students by ethnicity (White, Black, and Hispanic) in each state over the years from 2005 and 2015. At the national level, the achievement gap between White and Black students seemed to be greater than White and Hispanic students. Notably, there is a large achievement gap between White, Black, and Hispanic students over the years. In Minnesota and Ohio, the achievement gap between Hispanic and Black seemed to be closing toward 2015. Interestingly, in Colorado, the Black students' algebra scores appeared to be dramatically increasing between 2007 and 2009 followed by a substantial decrease between 2009 and 2011.

Wood, M. B., Turner, E. E., Civil, M., & Eli, J. A. (Eds.). (2016). *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Tucson, AZ: The University of Arizona.

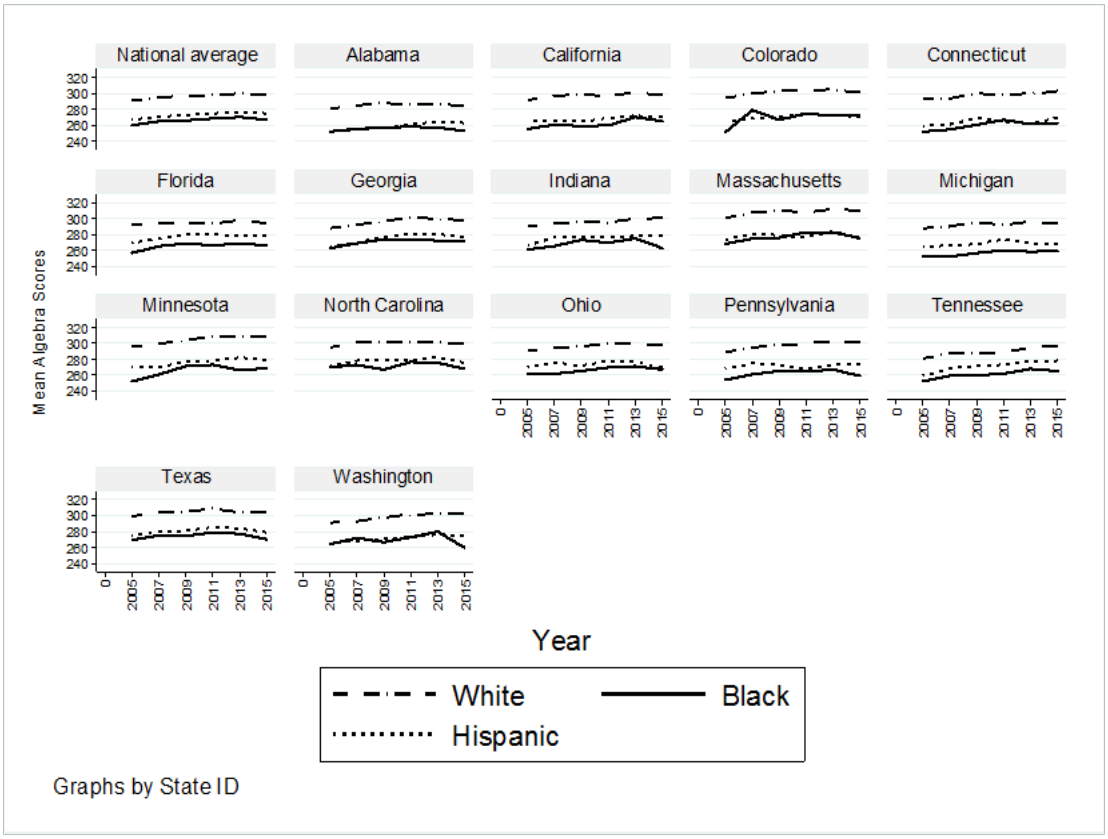

Figure 1. Algebra Achievement (Scores) by Race, 2005-2015.

A one-way ANOVA was conducted for the algebra score differences by race. The mean score for Black students was found to be lower than the mean scores for Hispanic and White students, and the mean score of white students was the highest. There were statistically significant difference in students' algebra scores between ethnicity groups, $F(2, 303) = 592.37$, $p <. 001$. A Post Hoc test result showed that there were significant differences between all race/ethnicity groups. A one-way ANOVA to determine differences in algebra scores by race/ethnicity across the years 2005, 2007, 2009, 2011, 2013, and 2015, was significant, $F(5, 300) = 2.98$, $p = .012$ for race/ethnicity over the years. Follow-up tests were conducted to evaluate differences among the means. The results indicated that the mean score of 2005 was significantly lower than the mean scores in the other assessment years. Additionally, the students' algebra scores were significantly higher in 2013 and 2011 than in the 2005 assessment year. The algebra scores by race/ethnicity increased from 2005 to 2013. However, the mean scores decreased from 2013 to 2015.

Lunch Eligibility

NAEP used student's lunch eligibility as a determinant of family income level. Students are eligible for free lunch if their family income is at or below 130 percent of the poverty level and are eligible for reduced-price lunches if their family income is between 130 percent and 185 percent of the poverty line. The findings show that there was a notable increase in the mean algebra scores for students who are not eligible for National School Lunch Program (NSLP) from 2005 to 2015 and also those eligible for free lunch. Massachusetts had the highest algebra scores in all their categories over the years when compared to the other states.

Wood, M. B., Turner, E. E., Civil, M., & Eli, J. A. (Eds.). (2016). *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Tucson, AZ: The University of Arizona.

A one-way ANOVA was conducted to evaluate differences for the students' algebra scores by NSLP eligibility among the 16 states from 2005 to 2015. The dependent variable was lunch eligibility, including "not eligible, reduced price lunch, and free lunch". The ANOVA test was significant, $F(5, 285) = 5.217$, $p < .001$, for the eighth grade algebra scores by lunch eligibility over the years. A follow-up test result showed that the algebra score of 2005 was significantly lower than the score for all the other assessment years. Further, the students' algebra scores were significantly higher in 2015, 2013 and 2011 than in the 2005 assessment year.

The result also shows that the mean score of the students who were eligible for free lunch (M = 270.06, SD = 6.86) was lower than the mean scores of the students who are eligible for reduced lunch (M = 280.75, SD = 6.84) and the students who were not eligible (M = 298.59, SD = 6.92). There were significant differences in the students' assessment scores between groups, $F(2, 288) = 46.899$, $p <. 001$.

Academic Resources at Home

Mother's Level of Education. An independent-samples t-test was conducted to evaluate the differences in the students' algebra scores by mother's education level, including two levels: did not finish high school and graduated from college. The test was significant, $t(202) = -29.66$, $p < .001$. The students whose mother graduated from college (M = 299.12, SD = 7.35) had higher scores than those whose mothers did not finish high school (M = 270.65, SD = 6.32). The 95% confidence interval for the difference in means was wide, ranging from 30.36 to 26.57. A one-way ANOVA of the algebra scores by mother's level of education showed no significant differences over the years.

Number of Books at Home. An independent-samples t-test was conducted to determine the differences in the students' algebra scores by the number of books at home over the years from 2005 to 2015 at two levels: less than 10 and more than 100. The test was significant, $t(202) = -41.56$, $p <$ .001. Students who have more than 100 books at home (M = 304, SD = 7.45) had higher algebra scores than those have less than 10 books at home (M = 264.25, SD = 6.14). The 95% confidence interval for the difference in means ranged from 41.60 to 37.82. A one-way ANOVA of the algebra scores by the number of books at home showed no significant difference over the years.

Languages other than English Spoken at Home

A one-way ANOVA was conducted to determine the differences that exist in the eighth graders' algebra scores by languages other than English spoken at home from 2005 to 2015. There was a significant difference in algebra score by language spoken at home over the years, $F(5, 401) = 10.187$, $p < .001$. Particularly, the mean algebra scores increased over the years; the lowest mean score was in 2005, and the highest mean score was in 2015. Follow-up tests showed a significant difference that (a) 2005 eighth graders had a significantly lower score compared to the other assessment years, and (b) 2007 had a significantly lower score compared to 2013 and 2015.

We also compared students' algebra achievement by language spoken at home. The post-hoc test result showed that students who spoke English most of the time at home had a significantly higher algebra score than those who spoke English less often. Similarly, students who spoke English half of the time at home had a significantly higher score to those who rarely spoke English at home.

Discussion

The purpose of this study was to examine the achievement gap among students across the 16 states over the years from 2005 to 2015. There were differences in eighth-grade algebra achievement based on SES, academic resources, race/ethnicity, and languages other than English spoken at home, over the years. An earlier study that examined students' mathematics achievement in different grades had similar findings (Hemphill & Vanneman, 2011; Vanneman, et al., 2009). This present study's results also suggest that the eighth-grade algebra score in 2005 was significantly lower than the

Wood, M. B., Turner, E. E., Civil, M., & Eli, J. A. (Eds.). (2016). *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Tucson, AZ: The University of Arizona.

algebra score in all the other assessment years. The improving algebra achievement scores over the years could be related to the adoption of the Common Core State Standards from 2010.

Although the students' average algebra scores continued to rise over the years, some significant differences persist. In particular, algebra scores differed significantly by race/ethnicity, SES, and languages other than English spoken at home. Specifically, the eighth- grade black students consistently posted significantly lower scores over the last ten years. Notably, in the last two years, ten of the selected states showed a drop in the black eighth-grade students' algebra achievement. The Hispanic students' algebra achievement dropped in six of the 16 states studied. In contrast, only five of the selected states showed a drop in the white students' algebra achievement. In general, there was an average drop in students' algebra achievement in the last two years. By highlighting the algebra achievement, it is evident that the Black and Hispanic students join high school with significantly lower algebra achievement scores. Similarly, students from families with lower income, and less academic resources, and those classified as having English as a second language join high school with lower algebra achievement. Indeed, other earlier studies also found that student algebra achievement scores were related to students' demographics, with notable achievement gaps across the different demographic groups (McCoy, 2005; Rakes et al., 2010). Thus, if students require knowledge of early algebra to be successful in further algebraic thinking learned in high school, it is evident that on average Black and Hispanic students could be joining high school with significant gaps needed for a successful transition to more complex algebraic reasoning.

The algebra achievement gaps should be further explored to show the related factors influencing these persistent patterns. Further, the opportunities that students have to learn algebra in high school could provide more information on the effect of these gaps in students' early algebra learning and future course taking patterns. Finally, the findings from this study suggest that early algebra achievement could be a factor related to the small representation of minority students in STEM fields.

References

Bjuland, R. (2012). The mediating role of a teacher's use of semiotic resources in early algebraic reasoning. *ZDM Mathematics Education, 44,* 665-675.

Blanton, M.L. & Kaput, J.J. (2011). Functional thinking as a route into algebra in the elementary grades. In J. Cai & E. Knuth (Eds), *Early algebraization*: *A global dialogue from multiple perspectives* (pp. 5-23). Dordrecht: Springer.

Cai, J. & Knuth, E. (2011). Early algebraization: A global dialogue from multiple perspectives. New York, NY: Springer.

Carraher, D.W., & Schliemann, A. D. (2007). Early algebra and algebraic reasoning. In F. K. Lester Jr. (Ed.), *Second handbook of research on mathematics teaching and learning* (pp.669-705). Charlotte, NC: Information Age Publishing.

Common Core State Standards Initiative. (2010). Common core state standards for mathematics. Retrieved from http://www.corestandards.org/

Kaput, J. J. (2000). *Teaching and Learning a New Algebra with Understanding*. Dartmouth, MA: National Center for Improving Student Learning and Achievement in Mathematics and Science.

Kieran, C. (2007). Learning and teaching of algebra at the middle school through college levels: Building meaning for symbols and their manipulation. In F.K. Lester, Jr. (Eds). *Second Handbook of Research in Mathematics Teaching and Learning* (pp. 707–762). Charlotte, NC: Information Age Publishing.

Hemphill, F. C., & Vanneman, A. (2011). *Achievement Gaps: How Hispanic and White Students in Public Schools Perform in Mathematics and Reading on the National Assessment of Educational Progress. Statistical Analysis Report.* (NCES 2011-459). Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

Howie, S. (2005). System-level evaluation: Language and other background factors affecting mathematics achievement. *Prospects, 35*(2), 175-186. doi:10.1007/s11125-005-1820-8

Lubienski, S. T. (2002). A closer look at Black-White mathematics gaps: Intersections of race and SES in NAEP achievement and instructional practices data. *Journal of Negro Education*, *71*(4), 269-287. doi: 10.2307/3211180

Lubienski, S. T. (2008). On "gap gazing" in mathematics education: The need for gaps analyses. *Journal for Research in Mathematics Education*, *39*(4)*,* 350-356.

Lubienski, S. T., Robinson, J. P. Crane, C. C. & Ganley, C. M. (2013). Girls' and boys' mathematics achievement, affect and experiences: Findings from ECLS-K. *Journal for Research in Mathematics Education, 44*(4), 634-645.

McCoy, L. P. (2005). Effect of demographic and personal variables on achievement in eighth grade algebra. *The Journal of Educational Research*, *98*(3), 131–135. http://doi.org/10.2307/27548070

McGraw, R., Lubienski, S. T., & Strutchens, M. E. (2006). A closer look at gender in NAEP mathematics achievement and affect data: Intersections with achievement, race/ethnicity, and socioeconomic status. *Journal for Research in Mathematics Education*, *37*(2), 129-150.

Rakes, C. R., Valentine, J. C., McGatha, M. B., & Ronau, R. N. (2010). Methods of instructional improvement in algebra. A systematic review and meta-analysis. *Review of Educational Research*, *80*(3), 372-400.

Reardon, S. F., & Galindo, C. (2009). The Hispanic-White achievement gap in math and reading in the elementary grades. *American Educational Research Journal*, *46*(3), 853-891.

Spielhagen, F. R. (2006). Closing the achievement gap in math: Considering eighth grade algebra for all students. *American Secondary Education, 34*(3), 29-42.

Vanneman, A., Hamilton, L., Baldwin Anderson, J., and Rahman, T. (2009). *Achievement gaps: How Black and White students in public schools perform in mathematics and reading on the National Assessment of Educational Progress*, (NCES 2009-455). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.

Warren, E. A., Cooper, T. J., Lamb, J. T. (2006). Investigating functional thinking in the elementary classroom: Foundations of early algebraic reasoning. *Journal of Mathematical Behavior*, *25*(3), 208-223.