Journal of Mathematics Education
June 2019, Vol. 12, No. 1, pp. 39-56

https://doi.org/10.26711/007577152790037

Informing Informal STEM Learning: Implications for Mathematics Identity in African American Students

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The purpose of this study was to assess the ability of informal science, technology, engineering, and mathematics (STEM) activities to influence the mathematics dispositions of African American students. The researchers aimed to elucidate the effects of out-of-school time (OST) STEM activities on the mathematics dispositions of African American students. A sample of African American students (N=3,518) was drawn from the High School Longitudinal Study (HSLS09/12). After propensity score matching, a MANOVA analysis was conducted to assess the differential effects of OST STEM on the mathematics dispositions of African American students. A significant main effect was found for OST participation, Wilks's $\lambda = .96$, $F(3, 1039) = 10.07$. *The results indicated an acute positive effect on mathematics identity for African American students who participated in informal STEM activities. This study contributes to the literature on the effects of informal STEM instruction by examining specific effects on African American students.*

Keywords: STEM, out-of-school time, informal learning, mathematics identity, African American students

It is imperative that the United States (U.S.) recruit, train, and retain a more diverse science, technology, engineering, and mathematics **(**STEM**)** workforce. Due to issues of workforce development in the U.S., thousands of STEM-related positions remain unfilled for lack of qualified workers every year (Atkinson, 2013). Many students enter colleges and universities seeking STEM degrees but fail to earn a degree related to these disciplines. This creates a compounding and persistent problem. Only 40% of declared STEM majors earn a degree in STEM, accounting for only 300,000 of the 1 million STEM workers necessary to fill positions within the STEM job market in the U.S. (Holdren & Lander, 2012). Furthermore, other projections have indicated that the number of culturally and linguistically diverse STEM professionals would need to triple to be representative of U.S. population trends (Schneider, Judy, & Mazuca, 2012). Because promoting the STEM career interests of a more diverse population of learners is a major goal reflected in the educational policy in the U.S., the implications of recent shortages in qualified STEM workers have consequences of universal concern.

The difficulty the U.S. has experienced in attempting to develop and sustain students' interests in STEM careers has raised concerns regarding the competitiveness of the U.S. economy (National Science Board, 2008). Some scholars have argued that an increase in the involvement of traditionally marginalized groups within STEM fields could bring unique contributions to help address the growing complexity of STEM needs for the 21st century (Chinn, 2002). Therefore, these issues are of particular concern to school personnel and parents of culturally and linguistically diverse learners. It is important that parents, policy makers, and school personnel understand issues regarding motivating students toward pursuing STEM and STEM careers, characteristics of individuals in STEM careers, and challenges and benefits to designing and implementing a STEM curriculum (Gallant, 2010). Equitable access to opportunities to learn is important, yet what remains unknown are the effects of participation in informal STEM enrichment on the content and career interest of large populations of diverse U.S. learners.

Increasing students' access to and participation in informal STEM enrichment is one way to increase STEM career interest. Unfortunately, research has shown that only 17% of 12th grade students are both proficient in mathematics and interested in majoring in a STEM field in college (Business-Higher Education Forum, 2011). The majority of students who lack sufficient STEM preparation historically come from culturally and linguistically diverse backgrounds. Yet, African American students and other underrepresented students of color have been found to possess the same level of interest (34%) in STEM majors as White students (Veenstra, 2010, p.16 quotation marks?). These trends suggest that educational settings vary in their ability to leverage a learner's existing interest and resources (Bell, Bricker, Reeve, Zimmerman, & Tzou, 2013). These achievement gaps are more or less gaps in opportunities for learning and quality of services available to some students (Woolley, Strutchens, Gilbert, & Martin, 2010). Informal STEM activities can serve as a means to address persistent gaps in opportunities to learn.

Student participation in authentic applications of science and mathematics through projects has been shown to promote their interest in science and mathematics careers (Rukavina, Zuvic-Butorac, Ledic, Milotic, & Jurdana-Sepic, 2012). Informal STEM activities can provide these opportunities when logistical constraints prohibit them in traditional classroom settings. Educational enrichment within informal STEM activities has substantial practical and empirical implications for culturally and linguistically diverse learners. Informal STEM learning exposes students to authentic learning experiences beyond the classroom walls. However, the differential effect of informal STEM participation on the academic dispositions of students of color in general, and African American students in particular, remains relatively unexamined in the literature. To address this concern, researchers in the current study examined the effects of informal STEM participation on the mathematics dispositions of African American students.

STEM Academic Dispositions

A student's STEM dispositions are intrapersonal correlates that relate to the student's capacity to succeed as a STEM learner and professional. Common disposition traits include STEM interest, identity, and self-efficacy. Interest in STEM can be described as one's positive inclination toward science, technology, engineering, and mathematics fields (Sahin, 2013). Empirical evidence has consistently suggested that interest within formal classroom settings and other educational settings correlate to career choice (Kuechler, McLeod, & Simkin, 2009; Tai, Liu, Maltese, & Fan, 2006). In comparison, STEM identity can be defined as the concept of fitting in within STEM fields. A more precise definition of STEM identity is an individual's ability to see himself or herself as the kind of person who could legitimately participate in STEM through his or her interest, abilities, race, gender, and culture (Ong, Wright, Espinosa, & Orfield, 2011).

Research findings have indicated that interest in STEM and STEM identity development are affected by one's perception of his or her abilities in the domain of mathematics and science—or mathematics and science self-efficacy (Hughes, Nzekwe, & Molyneaux, 2013). Self-efficacy, or one's beliefs concerning personal ability, has been found to be a predictor of academic performance and retention in STEM disciplines, specifically for women and people of color (Marra & Bogue, 2006). Together these intrapersonal correlates represent the psychosocial factors that support students' resilience in STEM activities. Promoting and sustaining positive STEM dispositions supports the preparation of diverse STEM learners. Fostering students' interest and competence in STEM disciplines is necessary to recruit and retain STEM professionals, because STEM competence is a significant predictor of student persistence. In addition, achievement in STEM must be recognized and rewarded to foster positive STEM dispositions (Beier & Rittmayer, 2009). For example, students who are STEM proficient and active in advanced courses have been found to be more likely to pursue STEM degrees (Sahin, Erdogan, Morgan, Capraro, & Capraro, 2013; Wang, 2012). Nevertheless, STEM interest and competence vary across race and gender based on students' experiences. These experiences influence the dispositions of students of color and require further examination.

Informal STEM Activities

Student participation in informal STEM activities helps increase their achievement and supports their development of positive STEM dispositions. The supports for informal learning opportunities focusing on STEM enrichment are widespread (DeCoito, 2014; Fenichel & Schweingruber, 2010). Today, informal STEM learning opportunities are primarily offered in the form of out-of-school time (OST) activities. Each OST activity affords students time, tolerance, safety, choice and affords educators the ability to incorporate emotional, aesthetic, and social elements into learning activities (Bevan & Michalchik, 2013). Typical informal STEM activities include after-school programs and summer camps. After-school programs include tutoring, mathematics clubs, and robotics competitions, whereas summer camp activities often include enrichment through non-traditional learning activities (i.e., museum visits and project-based learning). However, the quality and effectiveness of STEM OST activities can vary.

When appropriately executed, informal OST activities within a STEM context can be used to engage youth in rigorous, high-quality, and purposeful learning experiences (Gupta, Adams, & Dierking, 2011; Vandell, Simzar, O'Cadiz, & Hall, 2016; Young, Ortiz, & Young, 2017). This form of STEM enrichment supports student achievement in mathematics and science content. Secondly, enrichment programs have been shown to provide valuable experiences that foster students' interest in STEM topics and help students realize how STEM disciplines are connected to daily life experiences (Thomasian, 2011). These activities allow students to expand their STEM content knowledge. Finally, STEM enrichment provides instructional opportunities for traditionally marginalized populations that are otherwise not offered in many traditional school settings.

Opportunities to pursue STEM interests are not readily available in many schools serving students of color (Bell, Lewenstein, Shouse, & Feder, 2009). Informal STEM activities provide students exposure to learning experiences that can be impractical in many traditional school settings. For example, informal STEM activities afford students opportunities to reinforce practical connections by visiting museums and STEM-related businesses (Morana, Bombardier, Ippolito, & Wyndrum, 2012). Research has indicated that a decrease in STEM-related interests and aspirations emerges early among underrepresented populations in STEM such as girls and students of color (Watt & Eccles, 2008). Hence, early exposure to high-quality STEM instruction and enrichment is pivotal to developing and sustaining positive STEM dispositions amongst African American students.

Problem Statement

Large populations of students of color lack opportunities to explore advanced mathematics and science courses during high school (Tyson, Lee, Borman, & Hanson, 2007; Woolley et al., 2010). In much of the literature concerning opportunities to learn, scholars seek to promote access and equity to quality STEM instruction and resources (Boykin & Noguera, 2011). Yet, many African American students receive less than adequate STEM instruction. Racial achievement disparities influence the dispositions of students of color.

The impact of achievement gaps mediate the STEM persistence of students of color, and African American students specifically. Although racial achievement disparities are pervasive in U.S. schools, researchers in a previous study disrupted the common narrative about African American students' negative STEM dispositions; they found that African American females have positive attitudes toward learning science (Buck, Cook, Quigley, Eastwood, & Lucas, 2009). That said, much is known concerning the effects of misplaced opportunities, but far less is known about the effects of participation in STEM OST activities on African American students' STEM dispositions when opportunities are readily available and students participate.

Students of color are often likely to exhibit strong interest in STEM, even though they lack sufficient preparation in mathematics and science (Business-Higher Education Forum, 2011). Thus, it is important that researchers and educators assess students' STEM capacity based on performance, promise, and participation. Due to the persistence of achievement and opportunity gaps, sustaining positive STEM dispositions in African American students is critical for diversifying the STEM pipeline. The National Research Council (2013) has recommended going beyond academic achievement to assess STEM capacity. Thus, the purpose of this study was to focus on the impact of informal STEM participation on African American students' mathematics dispositions rather than on their achievement. The researchers of this present study sought to fill this void by examining how participation in informal STEM during OST affects mathematics-related academic dispositions of African American students. African American students were selected as the population of interest based on their historical and continual marginalization in STEM fields. The researchers intended for this examination to provide information that can be used to support increases in STEM career interest among diverse populations. Additionally, the results of this study offer researchers a deeper understanding of the influence of informal STEM activities on academic dispositions. This study was guided by the following research question: How does participation in informal STEM activities influence the mathematics dispositions of African American students?

Method

The participants in the present sample were African American students (N = 3,518) that had participated in the High School Longitudinal Study of 2009/2012 (HSLS:09/12) (Ingles et al., 2011). Students were randomly selected from a pool of over 21,000 students from 944 public, charter, and private schools in the U.S. The base year data collection included online surveys administered to students, parents, math teachers, and administrators. In subsequent administrations, similar online surveys were administered to parents and students. Some of these variables represent the independent and dependent variables examined in the present study. To assess the construct validity of the

HSLS:09/12, researchers conducted a principle component factor analysis (Ingles et al., 2011). In the present study, researchers examined the following mathematics disposition scales: (a) self-efficacy, (b) interest, (c) identity, and (d) utility. Each scale's properties and characteristics are presented in the subsequent sections.

Mathematics Disposition Scales

The mathematics self-efficacy items captured each student's perceived ability to perform in mathematics courses. The Mathematics Efficacy Scale (X2MTHEFF) consisted of four items on the survey. Students were asked to indicate whether they agreed or disagreed with item statements related to high school mathematics courses such as, "You are confident that you can do an excellent job on tests in this course". The four items were all Likert scaled from "strongly agree" to "strongly disagree". The Mathematics Interest Scale (X2MTHINT) followed a similar analytic structure. Four items were used to assess the students' overall interest in mathematics courses. Three of these items were Likert scaled, and one was dichotomously scaled "yes" or "no". One sample item read as follows, "You really enjoy math". Mathematics identity is characterized as the individual's view of himself or herself as mathematically inclined.

The Mathematics Identity Scale (X2MTHINT) was composed of two items. An example item from the identity scale was "You see yourself as a math person". The final scale was the Mathematics Utility Scale (X2MTHUTI). The Likert-scaled items prompted students to indicate, for example, whether they "strongly agree" to "strongly disagree" that mathematics is "Useful for everyday life". These four scales together represent student mathematical dispositions. A complete list of the included items and their reliabilities is presented in Table 1.

Measures of Participation in Informal STEM OST Activities

Three items were used to measure student participation in informal STEM activities. First, students were asked the following question: "Since the beginning of the last school year, which of the following activities have you participated in?" The student was then given the option to select all that apply from a list that included (a) Math Club (S1MCLUB), (b) Math Competition (S1MCOMPETE), and (c) Math Camp (S1MCAMP). These observed responses were aggregated to represent the composite outcome variable S1NOMSACT, which represented any participation in informal STEM related to mathematics.

Table 1
Reliability Analysis Scores of Student Disposition Scales

Scale	Number of Items	Reliability (alpha)
Mathematic Identity	2	.83
1. You see yourself as a math person		
2. Others see you as a math person		
Mathematics Utility	3	.74
1. What students learn in this course is useful for everyday life [fall 2009 math course]?		
2. What students learn in this course will be useful for college [fall 2009 math course]?		
3. What students learn in this course will be useful for a future career [fall 2009 math course]?		
Mathematics Self-efficacy	4	.87
1. You are confident that you can do an excellent job on tests in this course [fall 2009 math course]?		
2. You are certain that you can understand the most difficult material presented in the textbook used in this course [fall 2009 math course]?		
3. You are certain that you can master the skills being taught in this course [fall 2009 math course]?		
4. You are confident that you can do an excellent job on assignments in this course [fall 2009 math course]?		
Mathematics Interest	3	.86
1. You are enjoying this class very much [fall 2009 math course].		
2. You think this class is a waste of your time [fall 2009 math course].		
3. You think this class is boring [fall 2009 math course].		

SOURCE: U.S. Department of Education, National Center for Education Statistics, HSLS:09 Base-Year Field Test.

Analysis

The data were analyzed in a three-step process. First, the data were cleaned and weighted to adjust the error variances to account for the complex sampling procedures. The HSLS:09/12, like most NCES sample designs, was non-random and incorporated stratification and clustering that should be accounted for in the analytic procedure. Statistical methods such as multilevel structural equation modeling and hierarchical linear modeling (HLM) incorporate clustering, which alleviates the need to adjust for design effects (Thomas & Heck, 2001). The current analysis required the use of an average design effect based in WISTUDENT Weight. Student weights were normalized and then adjusted to account for design effects. This procedure was conducted to maintain the integrity of the data and to assure that the final error variances were correctly calculated (Hahs-Vaughn, 2003). Next, the data were subjected to a propensity score matching procedure in IBM Statistics 23 to create an analytical experimental group and control group comprised of ostensibly similar participants.

A propensity score is defined as the conditional probability of assigning a participant to a particular treatment or comparison group given a set of covariates (Rosenbaum & Rubin, 1983). The covariates used to generate the propensity scores in this study were the following: (a) X1LOCALE, which characterized the location or urbanicity of the sample member's base year school as either city, suburb, town, or rural, (b) X1FAMINCOME, a categorical variable that indicated the sample member's family income, (c) X1TXMTSCOR, which represented the math standardized score and provided a norm-referenced measurement of achievement, that is, an estimate of achievement relative to the population, and (d) X1SEX, which indicated the sex of the participant indicated on the student survey. These covariates were then used to calculate the probabilities of group membership or propensity score using a logistic regression bases procedure built into IBM Statistics 23. After the propensity scores were calculated for each participant, a conditioning strategy was applied to produce groups of similar means and distributions of propensity scores (Rosenbaum & Rubin, 1984). Three conditioning techniques are available to obtain statistically equal likelihoods of group assignment: matching, regression adjustment, and stratification (D'Agostino, 1998). None of the above methods have universal a priori superiority (Baser, 2006). However, using nearest-neighbor matching minimizes the mean squared error, when at most, two untreated subjects were matched to each treated subject (Austin, 2010). Therefore, for the purpose of this study, nearest neighbor matching on a specified caliper was applied. This procedure is used to sort members of the treatment group by their propensity score and matches each unit sequentially to a propensity score in the control group that has the closest propensity score (Thoemmes, 2012). The caliper represents a distance measure that informs the quality of the match between the treatment and control groups. A caliper of 0.25 standard deviations (d = 0.25) of a score represents a reasonable distance for reducing bias between groups (Stuart, 2010). After matching was completed, a post-matching analysis was conducted to evaluate the balance between the treatment and control groups on the identified covariates. Essentially, the propensity score matching technique helped to increase the "apples to apples" comparison between the treatment and control group. Finally, the participants' propensity-score matched mathematics dispositions were analyzed by multivariate analysis of variance (MANOVA) to assess group differences across the four disposition outcome measures.

Results

The propensity score analysis results are presented in Table 2. After propensity score matching, the final sample was reduced to N = 1,042, and participants were divided equally across the treatment and control groups. Statistically significant differences were observed between pre- and post-matching achievement scores on the standardized mathematics theta scores. However, after matching, the groups were more similar on the all of the remaining nominal covariates except locale (urbanicity), which remained statistically significantly different based on $\chi 2$. Pictorial representations of the pre- and post-matching nominal covariates are presented in the Appendix. These data indicated that participants were more similar than different on the identified covariates after propensity score matching. Thus, this finding substantiated the results of the propensity score matching procedure.

Table 2
Covariate Balance Pre-and Post-Matching on Covariates

	No OST		OST					
Interval Covariates	*M*	*SD*	*M*	*SD*	*t*	*df*	*p*	*d*
Pre-Matching Achievement	46.59	9.04	48.97	10.08	5.45	3516	.000	.44
Post-Matching Achievement	46.80	8.67	48.97	10.08	3.73	1042	.000	.44
Nominal Covariates				$\chi 2$	*df*	*p*		
Pre-Matching								
Family Income				33.02	12	.001		
Locale (Urbanicity)				16.79	3	.001		
Gender				4.25	1	.04		
Post-Matching								
Family Income				18.16	12	.11		
Locale (Urbanicity)				8.25	3	.04		
Gender				1.86	1	.19		

Means and standard deviations for the mathematics dispositions outcome measures are provided in Table 3. *MANOVA* analyses and follow-up tests were applied. A statistically significant main effect was found for OST participation, *Wilks's* λ = .96, $F(3, 1039) = 10.07$. This result indicated that there was a statistically significant difference between disposition outcome variables. The majority of the difference, however, was accounted for by the mathematics identity outcome measure. Follow-up analysis indicated that a statistically significant difference was observed for mathematics identity of

African American students that participated in OST activities $F(1, 1041) = 38.15$, $p < .001$, $d = .39$ [.26, .51].

Table 3
Means and Standard Deviations for Mathematics Dispositions

	No OST		OST	
	M	*SD*	*M*	*SD*
Identity	-.09	1.00	.29	.98
Utility	-.63	2.36	-.46	2.41
Self-efficacy	-.66	2.34	-.46	2.41
Interest	-.65	2.33	-.50	2.40

Discussion

The results of this study have important implications for diversifying the STEM pipeline and for future empirical studies. First, the results suggest that the majority of African American students did not participate in any OST STEM activity. Specifically, 2,996 or 85% of the African American students in the present study reported that they were not participating in any OST STEM activities. This trend was consistent across school location, with approximately 82% of students in cities, 87% of student in suburbs, 89% of students in towns, and 85% of students in rural areas reporting not participating in OST STEM activities. These findings suggest that issues related to access to OST STEM activities require further consideration before true equity can be achieved. This result resounds the call to increase scholarship in which the mathematics dispositions of African American students are further examined (Varelas, Martin, & Kane, 2013). These data will help to create a more holistic understanding of the factors that influence the mathematics persistence and performance of African American students.

Finally, the results of this study suggest that participation in OST STEM has a significant effect on mathematics identity for African American students. Mathematics identity was the only mathematics disposition uniquely affected by OST STEM participation. This is important because it suggests that OST STEM activities have a very precise effect on African American students' mathematics dispositions. This has specific implications for parents and teachers of African American students. According to previous research, African American students exhibit three intersecting identities that support their mathematics success: (a) racial identity, (b) disciplinary identity, and (c) academic identity (Varelas et al., 2013). Parents are instrumental in helping African American children apply and improve their mathematical knowledge through real-world activities that are focused on the development of mathematical concepts, positive self-concept, and mathematics identity through socialization (Hughes, Kiecolt, Keith, & Demo, 2015). Teachers also have a critical role and should provide African American students with opportunities to learn mathematics through culturally responsive pedagogy to support their students' development of disciplinary or mathematics identity.

Moreover, educators are significant contributors to the achievement socialization and mathematics identity of African American students. Specifically, teachers are uniquely suited to foster students' disciplinary identity or ability to conceive that one is a doer of mathematics. A mathematics identity is formed by one's beliefs about the following: "(a) ability to do mathematics, (b) the significance of mathematical knowledge, (c) the opportunities or barriers to enter mathematics fields, and (d) the motivation and persistence needed to obtain mathematics knowledge" (Martin, 2000). Participation in informal STEM activities such as camps and after-school programs are instrumental in a student's development of an overall academic identity or the ability to recognize oneself as a participant in academic tasks and classroom activities. These activities provide low stakes opportunities to learn in an informal setting and are more accessible to students with different learning styles.

Conclusion

The results of this study add further credence to the argument that the effect of OST STEM activities on mathematics dispositions should be more closely studied across culturally and linguistically diverse populations. This is most apparent in the area of mathematics identity as observed in the results of the present study. Additionally, more work is needed to increase access to and participation in OST STEM based on the participation patterns observed in this study. In conclusion, to redress the consistent and persistent lack of equal learning opportunities present across the U.S., it is imperative that parents, teachers, scholars, and STEM professionals unite to create a concerted effort to increase access to and evaluate participation in STEM for traditionally underrepresented populations. To recruit, retain, and sustain students of color in the STEM pipeline, more investigations of the effects of informal STEM and other population interventions must be conducted to support these under-researched populations.

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Appendix

Figure A1. **Bar graph of pre- and post-matching covariate distribution.**

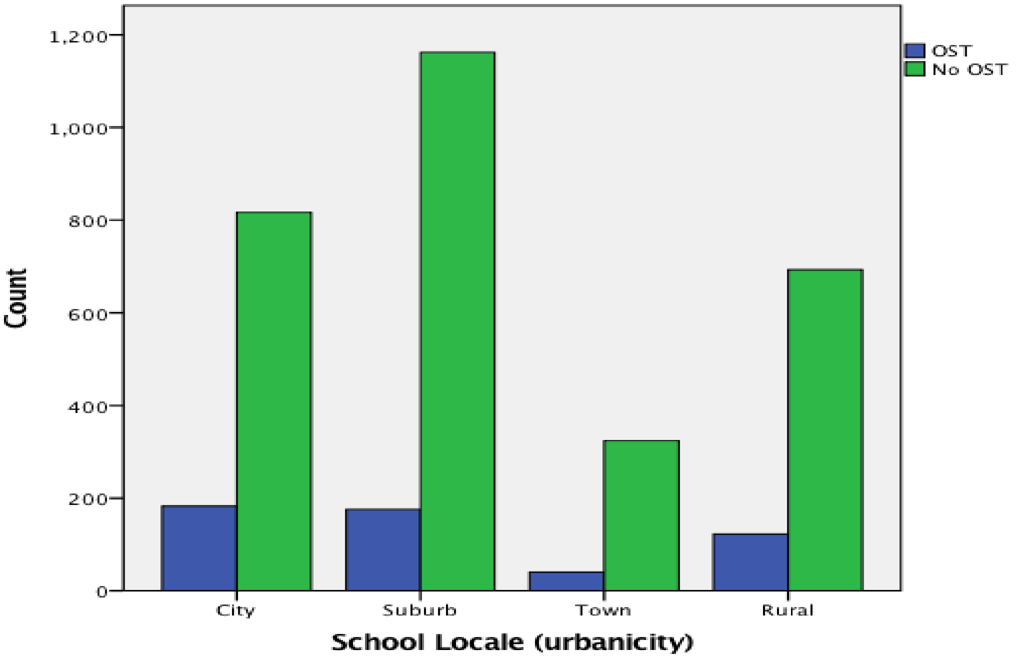

Figure A2. **Bar graph of pre- and post-matching covariate distribution.**

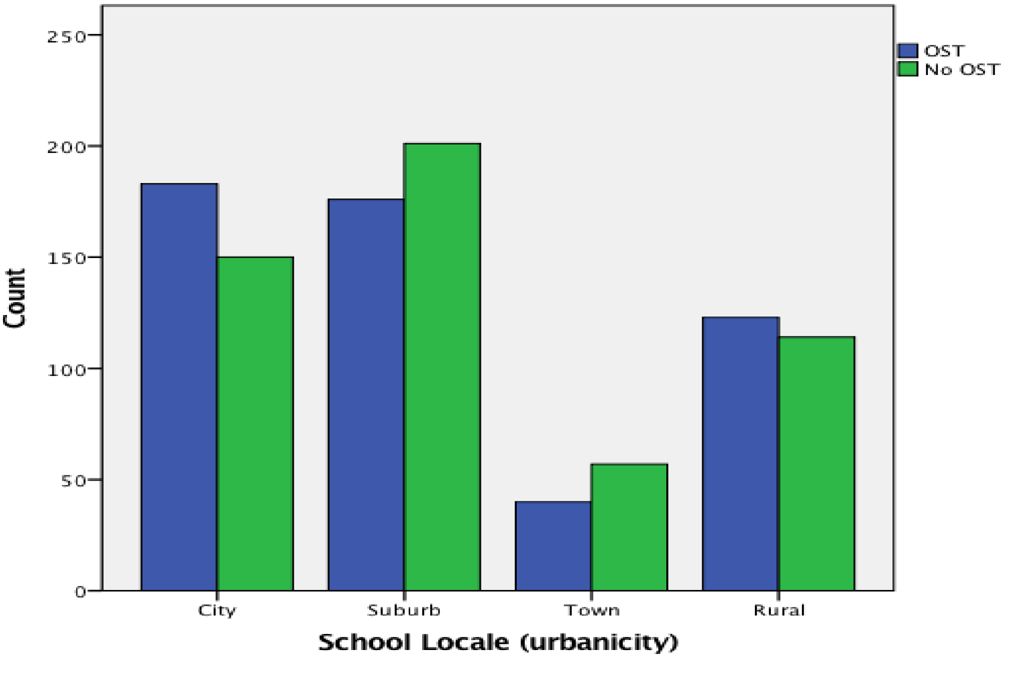

Figure A3. **Bar graph of pre- and post-matching covariate distribution.**

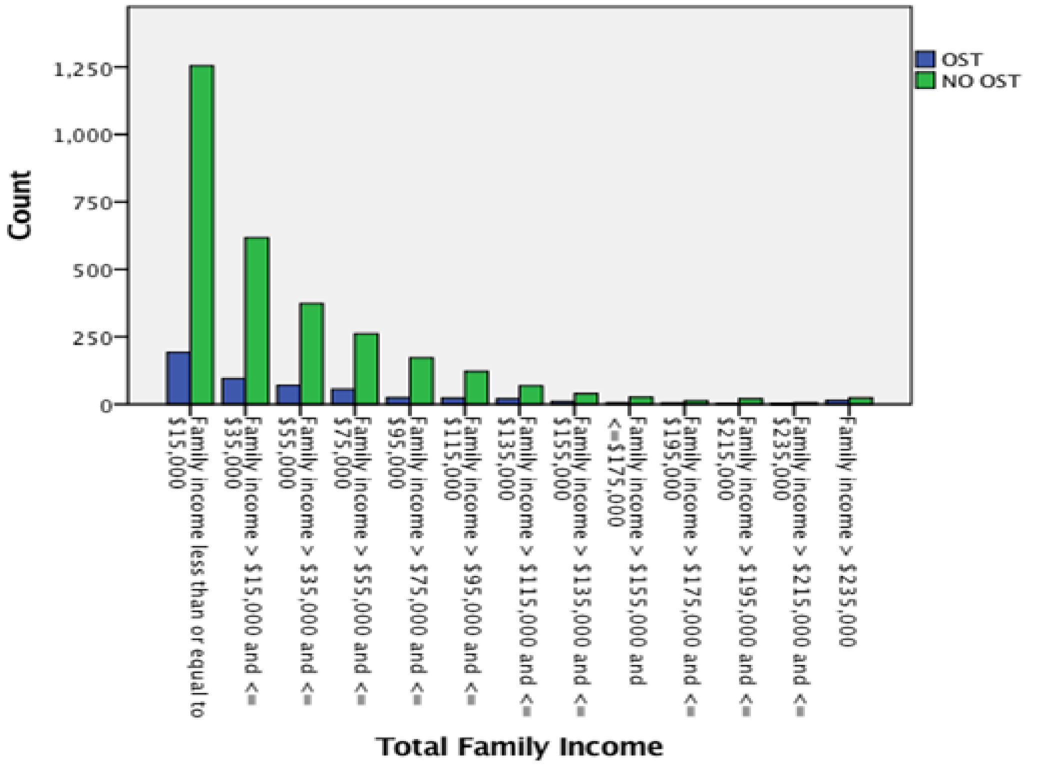

*Figure A4.***Bar graph of pre- and post-matching covariate distribution.**

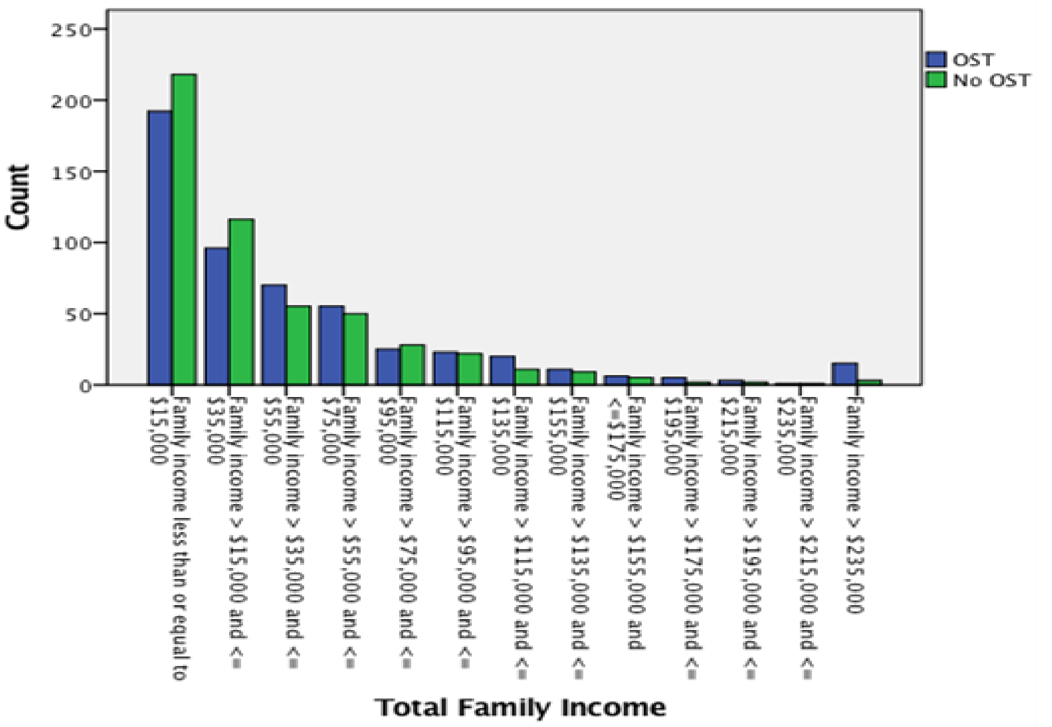

Figure A5. **Bar graph of pre- and post-matching covariate distribution.**

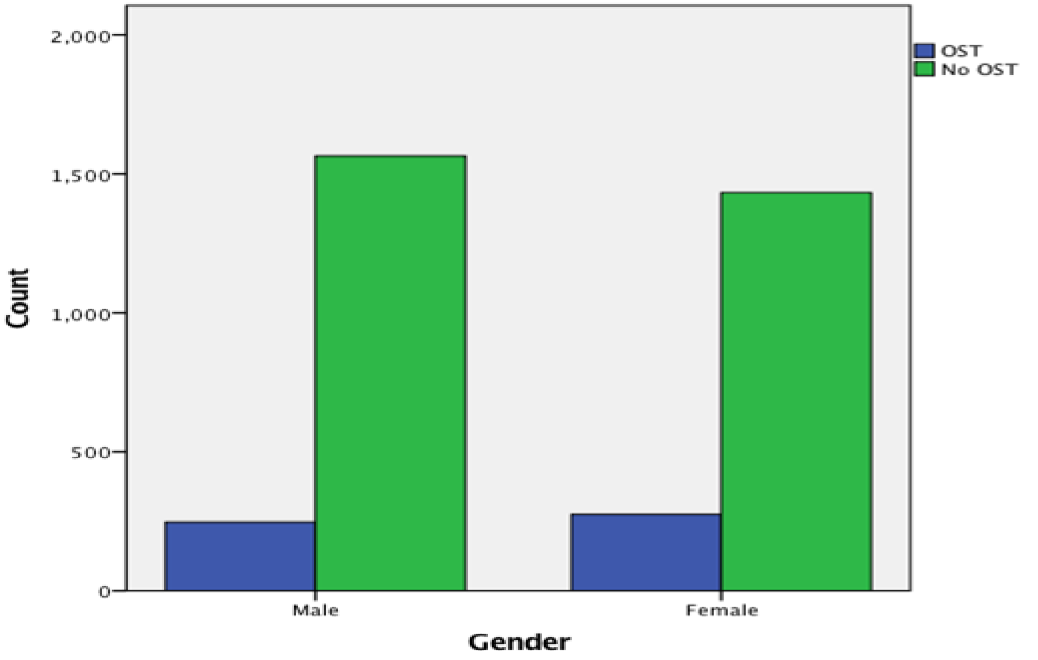

Figure A6. **Bar graph of pre- and post-matching covariate distribution.**