One-to-one technology and student outcomes*

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Abstract

New technologies offer many promises to improve student learning, but efforts to bring them to the classroom often fail to produce improvements to student outcomes. A notable exception to this pattern is one-to-one laptop programs. While early evaluations of these programs have been encouraging, they are costly to implement, and no study has investigated the impact of a one-to-one technology program implemented on a large scale over a multiyear period. With administrative school data, this paper uses a differences-in-differences strategy to evaluate the impact of a one-to-one laptop program implemented in a midsize school district. We find that while short-term impacts of the program were modest, math scores improved by 0.14-0.16 standard deviations in the medium term (4-5 years post-implementation). We also investigate the impact of the program on several measures of student behavior, finding that time spent on homework increased with implementation.

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1 Introduction

Educational technology offers many opportunities to innovate in and out of the classroom. Special software gives teachers more scope to customize lesson plans—challenging the advanced students while still offering extra help to students who are struggling. Encountering new technology at school can be especially important for poor and minority students, who often lag behind in computer and internet access at home. Moreover, we know that the workforce of the future must be able to adapt easily to new technologies for our economy to grow. Realizing the potential benefits, many schools and districts have sought to improve the technology they offer to teachers and students. When incorporating educational technology, the goal is not only to improve student learning in core subjects but also to increase computer skills.

In spite of its promise, the evaluations of programs to increase the presence of computer technology in schools and at home yield mixed evidence, with many null effects.[1] Theoretically speaking, the predicted effect of increased computer use is ambiguous because the prediction depends on the activities that computer use replaces.[2] Students may use the internet and computer software to conduct research and complete assignments more efficiently. They also might benefit from computer-adaptive instruction, which customizes lessons based on individual student needs. On the other hand, computers may distract students from educational pursuits through social networking, games, and other entertainment.

Most studies focus on improving access to technology at school or at home, but an increasingly popular intervention seeks to do both. One-to-one (or 1:1) technology programs traditionally provide one laptop or tablet to each student for use at home and at school. These programs are more intensive and more costly than most technology interventions, but initial evaluations show promise. Beginning in 2002, the Maine Learning Technology Initiative provided all 7th and 8th grade students in the state and their teachers with lap-

[1]Bulman and Fairlie (2016) offer a comprehensive review of technology in education.

[2]Several papers formally model the sources of this ambiguous prediction (see, for example, Fairlie, Bertran, and Das, 2010; Belo, Ferreira, and Telang, 2014).

top computers. Schools were equipped with wireless internet infrastructure, and teachers received professional development on incorporating laptop technology into the curriculum. Comparing 8th grade writing achievement before the initiative and two years after, an evaluation team found that scores increased by one-third of a standard deviation (Silvernail et al., 2011). Suhr et al. (2010) examine students in a suburban southern California school district who participated in a one-to-one program in 4th and 5th grades. While reading scores declined for 4th graders in the first year of the program, the authors find positive effects for reading for both grades in the second year. However, the treatment sample size of 54 students is very small. Shapley et al. (2010) evaluate the Texas Technology Immersion Pilot (TIP), which provided students in grades 6-8 at 21 treatment schools with laptops. Shapley et al. (2009) find that the program had no effect on reading test scores but that the program increased math test scores by 0.16 standard deviations at the end of two years and by 0.20 standard deviations at the end of three years. However, the program was not consistently implemented across treatment schools. Some schools restricted out-of-school laptop use, which goes against the goal of most one-to-one programs to increase access at home and at school. While the literature on one-to-one technologies is growing, it is still small relative to the body of research on computer and instructional technology in general. To our knowledge, this study is the first to investigate the impact on test scores of a one-to-one program implemented on a large scale over a period of more than three years.

Our study is also related to research that investigates heterogeneity in the impacts of technology interventions or the impact of technology on intermediate inputs. In their review article, Bulman and Fairlie (2016) note that few studies highlight heterogeneity in treatment effects for school-based interventions and speculate that this omission comes from the large number of studies finding no effect overall. In studies of home computer use, most find no differential impact by gender (Fairlie, Bertran, and Das, 2010; Malamud and Pop-Eleches, 2011; Fairlie and Robinson, 2013; Fairlie, 2016).[3] The same is generally true of impacts by

[3]Attewell and Battle (1999), which finds a larger impact for boys, and Fiorini (2010), which finds a larger impact for girls, are exceptions.

race or ethnicity (Fairlie, Bertran, and Das, 2010; Fairlie and Robinson, 2013; Fairlie, 2016).[4] Finally, Fairlie and Robinson (2013) and Fairlie (2016) find no evidence that treatment effects vary by prior achievement. To our knowledge, the main evidence on the effect of technology interventions on intermediate outcomes comes from Fairlie and Robinson (2013).[5] Along with a null impact on academic outcomes, they also report that the intervention had no effect on time spent on homework or unexcused absences.

In this paper, we evaluate the impact of the Digital Conversion Initiative in the Mooresville Graded School District on student outcomes. Beginning in 2008, the Mooresville district distributed laptop computers to every student 4th grade and up. At the same time, the district trained its teachers in ways to take advantage of this new technology in their lesson plans. Several thousand students were exposed to the program over the course of five years.

With administrative data on the universe of students attending public school in North Carolina, we use a difference-in-differences strategy to determine whether student outcomes improved with the implementation of the laptop program in Mooresville. We focus on math and reading achievement for students in grades 4-8, but we also examine the impact of the program on student behavior, such as time use and absences. While the short-term impacts of the program were modest, we find that math scores in Mooresville improved by 0.14-0.16 standard deviations in the medium term (4-5 years post-implementation) relative to the statewide trend. Reading scores also rose significantly, but by a smaller margin. These results are robust to using school districts in neighboring counties as the control group and eliminating transfer students from the sample. The difference between the short-term and medium-term impacts highlights the importance of long evaluation periods for technology programs. We also present evidence suggesting that the initiative had a larger impact on underrepresented minority students. The program had similar impacts for male and female students, and the evidence on whether students benefitted differentially by ability is mixed.

[4]Exceptions are Attewell and Battle (1999), which finds larger impacts for whites, and Fairlie (2012), which finds larger impacts for minority students in a community college setting.

[5]Vigdor, Ladd, and Martinez (2014) find some evidence that increased evidence to broadband internet increases time spent on homework.

Further analysis indicates that the program caused changes to student behavior, which may have contributed to rising achievement in the district.

The results in the paper provide new evidence that one-to-one technology programs are an effective means to raise student achievement. However, there may be a short-term adjustment period before gains are realized. While one-to-one programs are expensive, the effect sizes estimated here are large enough that they may still pass a cost-benefit test. The Mooresville school district was able to cover almost all of the program cost with its operating budget, suggesting that other districts can implement similar interventions without the need to seek outside funding. In Mooresville, the increase in test scores was accompanied with more time studying, indicating that student behavior may be a key mechanism through which new technologies might affect student performance.

The remainder of the paper proceeds as follows. The next section provides a summary of Mooresville's Digital Conversion Initiative. Section 3 describes the North Carolina education data and the difference-in-differences methodology. We present results on the impact of the initiative on test scores and explore potential mechanisms in Section 4. Section 5 concludes.

2 Mooresville's Digital Conversion Initiative

The Mooresville Graded School District is one of a handful of city school districts in the state of North Carolina. The city of Mooresville is located about 25 miles north of Charlotte and is part of the state's Piedmont region. Roughly 5,800 students were enrolled in the district in the 2012-13 academic year across the district's seven schools: three elementary schools serving grades K-3, two intermediate schools serving grades 4-6, one middle school serving grades 7-8, and one high school serving grades 9-12.

Superintendent Mark Edwards launched the Digital Conversion Initiative in 2007, and in the months leading up to the initial implementation, the district took several steps to prepare for the transition.[6] To test its network capacity, the district provided 400 MacBook laptops to

[6]Information on the Digital Conversion Initiative comes from several sources. District administrators,

the English department at Mooresville High School for students to use during class time only. The district also distributed laptops to all teachers and encouraged them to test them out. In January 2008, the district launched professional development seminars for teachers. These seminars provided teachers with training in specific programs, such as iMovie, and allowed teachers to share ideas for incorporating computers into their classrooms. The district also added five professional development half days and conducted a four-day summer institute attended by about one-quarter of teachers.

In August 2008, the district distributed laptops to all students at the high school and all students at one of the intermediate schools. The district expanded the program in August 2009, distributing laptops to students at the middle school and at the other intermediate school. Thus, every student in grades 4-12 received a laptop at the start of the 2009-10 school year. The district further expanded the program in August 2011 by providing laptops to all 3rd grade students for in-school use only. Students are required to return their laptops at the end of each academic year and therefore cannot use their laptops over summer vacation.

To cover some of the costs of the program, the district charges parents an annual technology usage fee of $50 per child, although the fee is waived for roughly 18 percent of low-income families. To guard against equipment damage, the district also provides students with a hard plastic MacBook case and a high-quality backpack with a padded laptop compartment. If a student damages or loses his laptop, his family is required to pay for the cost of repairing or replacing the equipment. If a family cannot afford to pay this cost, the student may borrow a laptop from the district for in-school use only. At the beginning of each school year, parents and students are required to attend a training class on operating and caring for the equipment.

Wireless internet access is ubiquitous on school grounds. To provide students with greater internet access after school, the district extended the hours that school buildings are open

most prominently the superintendent, have published pieces on the initiative (Edwards, Smith, and Wirt, 2012; Edwards, 2013). We also draw information from reporting in the popular press and in education trade publications (Farrell, 2013; Quillen, 2011; Schwarz, 2012; Helms, 2013). Finally, one of the authors toured the district in October 2012.

and collaborated with town officials to offer free wireless connections in libraries, community centers, municipal buildings, and parks. The district also partnered with a local broadband service provider to offer reduced rates on internet service for low-income families in the district. To ensure that students without internet connections at home are not disadvantaged, the district asks teachers not to assign homework that requires students to use the internet.

In its Responsible Use Policy, the district prohibits "personal use of school district technological resources for amusement or entertainment" (p. 2).[7] In addition to restricting inappropriate content, the district has blocked students from accessing many gaming and social media websites, including Facebook and Twitter. The district also prohibits students from using their laptops for commercial activities, such as buying or selling merchandise, and forbids students from using their laptops for political purposes. Students are allowed, however, to download music and videos, provided that they do so outside of school hours, that they do not violate copyright laws, and that the content is not deemed inappropriate. The district requires that students fully charge their laptops every night.

The district states that "no right of privacy exists in the use of technological resources" for teachers or students (p. 5). School personnel are allowed to monitor files and communications "accessed, downloaded, created or transmitted using school district technological resources," including e-mail messages and internet browsing histories (p. 5). When students are using their laptops at school, administrators can view students' computer screens in real time. One Assistant Principal at Mooresville Middle School spends 15 minutes after lunch every day monitoring students' computer screens.

The district reports that the Digital Conversion Initiative has prompted teachers to adopt a "flipped classroom." In traditional classrooms, teachers lecture during school hours and students complete assignments to practice and reinforce the material after school. In flipped classrooms, teachers record lectures on videos and assign students to watch them as homework. Students then spend class time completing assignments, either individually or in

[7] The Responsible Use Policy can be found at http://nela2.weebly.com/uploads/3/0/7/9/30795203/mgsd_rup.pdf.

small groups, while teachers circle the classroom to answer questions and provide additional help. Because teachers record their lectures rather than deliver them to every student in their class on the same day, students can work at their own pace.

Technological tools include not only the computers themselves but also the programs and resources available on the computers and on the internet. One program, icurio, provides more than 330,000 digital resources to students and teachers. Students can access a wide array of educational resources, such as games, videos, simulations, and activities. Teachers can view lesson plans, design multimedia presentations, assign projects, and administer tests. Online discussion boards and video conferencing programs allow students and teachers to communicate after school. Students can collaborate on group projects, and teachers can host review sessions prior to tests. These new tools also allow teachers, parents, and administrators to better track students progress. Online assessments save teachers time that they would have otherwise spent grading and provide teachers with immediate feedback on how well their classrooms and students understand the material. Using this information, teachers can modify their lesson plans or focus their attention on particular students. Parents can easily monitor their child's performance. Administrators can also use this information to identify the students who are near the threshold of passing a state assessment and to provide these students with additional help.

To make room for these new tools, the district decreased spending on print textbooks, calculators, encyclopedias, globes, and maps. The district also saved money by closing computer labs. The Digital Conversion Initiative costs about $1 per student per day, exclusive of infrastructure. In other words, this amount includes expenses for software programs, hardware, digital subscriptions, maintenance, and training. The district's operating budget covers 98% of the cost of the program, but it has also relied on funding from community sources. Most notably, Lowe's Home Improvement, which is headquartered in Mooresville, provided $250,000 in the early stages on the conversion.

3 Data and Methodology

3.1 Data

The data for this study come from the North Carolina Education Research Data Center (NCERDC), which compiles files from the North Carolina Department of Public Instruction (NCDPI). This data set is well-suited for the purposes on this study because it covers the universe of students attending public school in North Carolina for several years before and after the Digital Conversion Initiative. With these records, we can contrast outcomes for the students in Mooresville Graded School District with students in the rest of the state, both before and after the initiative.

The main analysis in this paper uses the End of Grade (EOG) test scores. Every North Carolina student in grades 3-8 takes standardized math and reading tests at the end of the school year, usually in May. Since the Digital Conversion Initiative targets students in grades 4 and up, we focus on grades 4-8. The files for 2006, 2007, and 2008 offer three years of pre-initiative data; the 2008-09 academic year is a transition year when the initiative was partially implemented; and the files from 2010-2013 provide post-initiative data. This data set includes over 4 million student-year observations, of which about 2,000 come from Mooresville in each year. We standardize test scores to be mean zero, standard deviation one, by subject, grade, and year, as is common in the test score literature. The EOG files also contain information on student ethnicity, gender, and age rounded to the nearest month. Each student is assigned a unique master identifier, and thus it is possible to follow students across time, even as they change schools. We pull time-varying school characteristics from the Public School Universe files and create a variable for the percentage of students eligible for subsidized lunch and a set of school ethnic composition variables.[8]

We make use of various NCERDC files to investigate the impact of the Digital Conversion Initiative on student behavioral outcomes. Time allocation is an important mechanism

[8]These files contain a pupil-teacher ratio variable, but it was discontinued in the 2010-11 school year.

through which the laptop program could affect achievement. Up to 2011, students reported their time use for the following activities at testing time: using a computer at home, working on homework, and free reading. In the raw data, the response options for time use are given in ranges. We convert these ranges to a continuous scale using the midpoint of the range when relevant; for the top option, we use a value close to the lower bound. For computer use, the student had the option to indicate that he does not have a computer at home, and for homework time, he could report that his teacher does not assign homework. In both of these instances, we convert the response to zero. In Appendix Table A.1, we report the original categorical responses, their frequencies, and the conversion scale. Another potential mechanism is a reduction in absenteeism. The variable for days absent is available until 2012.

3.2 Methodology

We use a difference-in-differences strategy to identify the impact of the Digital Conversion Initiative on student outcomes. Because we consider a span of eight years and have a large sample in each year, we allow for differential program impacts in each year. This more flexible specification lets us differentiate short-term and medium-term effects of the program, and it lets us determine whether our conclusions are sensitive to the choice of the base year. We specify the production of outcome y for student i attending school s in year t as:

$$y_{ist} = \sum_{t \neq 2008} \alpha_t * 1[year = t] * Mooresville_{it} + x_{it}\beta + z_{st}\delta + \gamma_s + \varepsilon_{ist} \tag{1}$$

where the vector α contains the parameters of interest. We use the 2007-08 academic year as the omitted time period since it was the last year before the Digital Conversion Initiative was implemented. Thus, 2006 and 2007 give us two snapshots of how Mooresville fared relative to the rest of the state before implementation. In 2009, the first year of implementation, only students in one of the middle schools had laptops, but by 2010, all Mooresville students in our sample had laptops. Each of the years from 2010 on tell how Mooresville students diverge from state trends. We also control for student characteristics x_{it}, which include ethnicity, gender, and age-for-grade, and for time-varying school characteristics z_{st}, namely the ethnic composition of the school and the proportion of students eligible for subsidized lunch. The school fixed effect γ_s captures persistent differences across schools in the outcome. Unlike the textbook set-up for difference-in-differences, we do not give the Mooresville district an indicator because the school fixed effects subsume any district-level effects. For test score regressions, we do not include year or grade indicators since we standardize these outcomes by grade and year; we do include them when the outcome is not standardized. Standard errors are clustered at the school district level.

The parameter α_t is interpreted as the impact of attending school in the Mooresville school district $|t - 2008|$ years before or after the initial implementation of the one-to-one laptop program. For this analysis, we have opted for a contemporaneous specification over a value-added specification.[9] While the value-added specification offers the advantage of including a proxy for endowed ability and past inputs, the interpretation of the parameters of interest becomes less straightforward. Many students were exposed to the program for a series of years, and for these students, lagged outcomes include the impact of the laptop program in previous years. Instead of thinking of the policy intervention as occurring on the student level, we emphasize the districtwide implementation of the program. In this paper, we ask whether the one-to-one laptop program caused outcomes to change for a school district relative to what we would expect from the statewide trend and the district-level baseline. This formulation is most relevant for policymakers who are considering implementing a one-to-one laptop program on a large scale, such as districtwide or statewide.

[9]See Todd and Wolpin (2003).

4 Results

4.1 Descriptive results

A simple comparison of mean test scores offers the first evidence of the effectiveness of the laptop program. In Table 1, we report sample means for Mooresville and the rest of North Carolina at three time intervals: pre-initiative (2006 and 2007), short-term post-initiative (2010 and 2011), and medium-term post-initiative (2012 and 2013). Mean test scores for the rest of North Carolina are close to zero for each time period due to normalization. In the pre-initiative period, Mooresville students scored 0.2 standard deviations higher in both subjects compared to the rest of the state. Because Mooresville students on average performed better on achievement tests before implementation, it is important to difference out their baseline achievement. In the short term relative to the baseline, Mooresville students scored 0.08 standard deviations higher in math but did not show any significant change in reading. In the medium term, they outperformed the state trend by 0.15 standard deviations in math and 0.04 standard deviations in reading. From this descriptive evidence, the Digital Conversion Initiative is associated with significant improvements in math, which become larger over time. In reading, the short-term and medium-term effects are not substantially different, and only the medium-term effect is statistically significant relative to the baseline.

The next set of rows in Table 1 contains sample means for demographic characteristics. These variables are important to include as covariates in our difference-in-differences analysis if they are trending differentially. In the pre-initiative period, 56% of students in the rest of North Carolina were white, 29% were black, 9% were Hispanic, and the rest were another ethnicity or multiracial. Almost half of this sample is female and the average age is about 12.5 years old. In contrast, Mooresville students in the pre-initiative period were less diverse: 77% were white, 15% were black, and 4% were Hispanic, with the remainder marking some other ethnicity. Comparing the pre-initiative columns to the short- and medium-term columns for Mooresville and the rest of the state, we see that the demographic variables carry some time trend. The last two columns test whether they are trending differentially. The two variables that are highly statistically significant are black and Hispanic. Over time, the proportion of black students in North Carolina has shrunk. While the same has been true in Mooresville, this trend has happened at a significantly slower rate. For Hispanic students, the share has grown statewide, but growth has been slower in Mooresville relative to the rest of the state. While we do not have strong evidence that any other student background variables are trending differentially, we still include them in the regression results for precision.

In the final set of rows in Table 1, we analyze mean differences in time-varying school characteristics. The proportion of students eligible for subsidized lunch is a measure of the socioeconomic status of the students in a school. In the rest of North Carolina in the pre-initiative period, the average student attended a school where 45% of students were eligible for subsidized lunch. In Mooresville, the average was 31%. Note that the variation in school characteristics for Mooresville only comes from three schools. At baseline, the students in Mooresville came from higher income families compared to the rest of North Carolina. In the short term, there were increases in the average proportion eligible for subsidized lunch in Mooresville and the rest of the state, but the increase in Mooresville was larger. In the medium term, the average proportion further increased in North Carolina, but it dropped slightly in Mooresville. In sum, there is evidence that the poverty rates in Mooresville and the rest of North Carolina trend differentially, but the direction of the difference in trends is different for the short term and medium term. We also report mean ethnic composition in Table 1 for the three largest ethnic groups (white, black, and Hispanic). These means and their trends mirror the student-level means and trends for ethnicity. Since these school-level characteristics trend differentially, they are important to include as control variables in our regression analysis.

4.2 Regression results for test scores

Our regression results show the potential for one-to-one technology programs to increase achievement in the medium term. In Table 2, we present these results for achievement scores, which come from estimating equation (1). We plot the coefficients for Mooresville interacted with year in Figure 1 for math scores and Figure 2 for reading scores. The regression results control for student demographics, time-varying school characteristics, and persistent differences across schools via school fixed effects, and they allow the laptop program to have a separate impact for each year. Standard errors are clustered at the school district level. The year 2008 is omitted, so program impacts are relative to 2008. Recall that 2008 is the last year before the Digital Conversion Initiative was implemented, though it was only partially implemented in 2009. We do not include 95% confidence intervals on these graphs. The standard errors for the coefficients of interest are so small that the confidence intervals would be indistinguishable from the point estimates, given the scale of the graphs.

Math scores in Mooresville are similar in the period 2006-2010. While many of these coefficients are statistically different from each other due to the large sample size, the effect sizes themselves are relatively small. However, Mooresville students trend away from the rest of the state by 0.09 standard deviations in 2011, 0.14 standard deviations in 2012, and 0.16 standard deviations in 2013. While the Digital Conversion Initiative had a relatively smaller impact on math scores in the short term, we find more substantial impacts in the medium term. As a point of comparison, the medium-term impacts are about one-fourth the size of the black-white test score gap. The medium-term impact is also similar to the effect of assigning every student in the district a teacher that is one standard deviation higher in quality (Chetty, Friedman, and Rockoff, 2014).

On reading tests, we find that Mooresville students score similarly, practically-speaking, in the years immediately before and after program implementation. The program impact grows to 0.07 standard deviations in 2011 and 0.12 standard deviations in 2012. While these effect sizes are meaningful, they are not quite as large as the math impacts in the same years.

In 2013 the impact of the laptop program fell to 0.06 standard deviations; the reason behind this reversal is not clear. The remainder of the coefficients in Table 2 have the expected sign and magnitude.

A potential concern for the test score results is that there may be selection into which students are administered the standardized test. The data files provided by the NCERDC include records for students who have a missing EOG test score. Three percent of student-year records have a missing or invalid math score, while 3.6% have a missing or invalid reading score. We estimate equation (1) with missing math score and missing reading score as the outcome and present the results in the first two columns of Appendix Table A.2. Many of the interactions of Mooresville with year are found to be statistically significant, which is not surprising due to the large sample size. Relative to the base year 2008 and the state trend, Mooresville students are more likely to be missing a test score in 2010 and 2011, equally likely in 2012, and less likely in 2013. Given the small rate of missing test scores overall and the mixed findings on missing test scores for Mooresville in Appendix Table A.2, we conclude that selection into taking the standardized tests is not a major concern for our interpretation of the results.

4.2.1 Heterogeneity

We explore whether the test score results vary by grade, gender, ethnicity, and prior performance. Most of the previous literature on technology interventions at home and at school find no evidence of heterogeneity in impacts. Since the strongest effects of Mooresville's laptop program were found for math scores, we focus on this outcome.

Results may differ by grade if students in certain grades, or their teachers, are more effective at utilizing laptops for human capital enhancing activities. For example, customizable lessons may be more advantageous for students in lower grades, before they are traditionally tracked into math classes by ability. Alternatively, older students may be more likely to be distracted by social media and gaming sites. Table 3 gives math results for regressions estimated separately by grade; Figure 3 illustrates these results. Overall, there is no clear pattern by grade. In 2012 and 2013, all program impacts by grade are positive, but they range from 0.04 to 0.25.

Program impacts may also vary by student characteristics, like gender and ethnicity. We estimate models that include triple interactions of Mooresville, year, and a selected student characteristic. In Table 4 and Figure 4, we show that students do not benefit from the laptop program differentially by gender. The triple interactions of female, Mooresville, and year, are not statistically significant in 2011, 2012, or 2013. This evidence is consistent with other studies that find that home computers do not impact boys and girls differently, such as Fairlie (2016). However, in this instance, we find that both boys and girls experience positive impacts, but that one gender does not benefit more than the other.

Table 5 presents triple interaction results for student ethnicity. We illustrate trends in impacts for the three largest ethnic groups (white, black, and Hispanic) in Figure 5. We find significantly larger program impacts for black and Hispanic students relative to whites in the years 2011 and 2012, and in 2013 only for Hispanics. For blacks, these differential positive impacts range from 0.02 to 0.09 standard deviations; for Hispanics, the range is 0.08 to 0.11 standard deviations. The base impact for whites in these years ranges from 0.07 to 0.15. Thus, the impact of the laptop program for Hispanic math scores is at least one-and-one-half times as large as the impact for white math scores. These results indicate that one-to-one laptop programs can be a key tool to reduce racial and ethnic inequality in achievement. However, the triple interactions for the pre-initiative years of 2006 and 2007 suggest that the program impacts are sensitive to the choice of base year and thus should be interpreted with caution. On the other hand, the triple interactions for 2009 and 2010, when the program was newly implemented, are not as different from the chosen base year of 2008, which suggests that these underrepresented minority students did indeed trend away from white students in Mooresville after the laptop program had been fully implemented.

Finally, we examine whether program impacts vary by baseline student performance.

One of the advertised benefits of technology programs that incorporate computer-adaptive technology is that lessons are more easily customizable. While teachers in traditional classrooms may be forced to teach to the middle of the ability distribution, technology may help students work at their own pace. If this is the case, we would expect the Digital Conversion Initiative to benefit the upper and lower tails of the ability distribution more than the middle 50% of the distribution. In our analysis, we divide students by their place in Mooresville's math score distribution in the previous year. We present these triple interaction results in Table 6 and Figure 6. The evidence on whether high- or low-ability students benefit more from the laptop program is mixed, and conclusions are sensitive to the choice of base year. Even if a technology intervention offers more in-class benefits to students at the ends of the distribution, it is possible that these students experience more distraction from technology at home so that the school and home impacts cancel each other out. Still, this evidence casts doubt on the claim that technology helps teachers teach to the entire distribution of students. Furthermore, if teachers or administrators are using technology to target students on the margin of passing state assessments, this evidence indicates that the targeting was not effective.[10]

4.2.2 Robustness

We explore whether the test score results are robust to an alternative control group and whether estimates might be contaminated by transfers. Again, we focus on math scores for these robustness checks.

It is possible that the rest of North Carolina is not a valid control group for Mooresville. The identifying assumption for difference-in-differences estimation is that Mooresville students would have been on the same trajectory as the rest of the state had the laptop program not been implemented. In other words, Mooresville and the rest of the state must be on "parallel paths." While we have no specific reason to believe that the rest of North Carolina

[10] This targeting behavior would be consistent with Neal and Schanzenbach (2010).

is a poor choice for a control group, it is true that North Carolina is a diverse state with some regional differences.[11] We replicate our math score results with a control group that might match Mooresville more closely on unobserved characteristics. We define our alternative control group as the students attending schools in the counties surrounding Iredell County, except Mecklenburg County,[12] plus the students attending schools in Iredell County that are not part of the Mooresville Graded School District.[13] We do not include Mecklenburg County in the alternative control group because it includes the major urban area of Charlotte.

In Appendix Table A.3, we provide descriptive statistics for the alternative control group contrasted with Mooresville. The mean difference-in-differences for math and reading suggest larger program effects for these outcomes. Compared to the entire state, the baseline demographics for the neighboring counties more closely mirror those for Mooresville; in addition, there is less evidence that the student demographic variables are trending differentially. School proportion subsidized lunch does trend differently for Mooresville and its surrounding area; however, this is also true for Mooresville and the rest of the state. Taken together, this evidence suggests that the neighboring counties may be a better control group for Mooresville.

We restrict the sample to Mooresville and neighboring counties and present regression results for math scores in the second column of Table 7. The first column shows results for the full sample. The program impacts are almost identical but are sometimes higher when neighboring counties are used as the control group. Thus, choosing a control group that arguably provides a closer match to the Mooresville school district does not alter our conclusions; if anything, we may be understating effect sizes by relying on the entire state as

[11] North Carolina is often divided into three major regions: the Atlantic Coastal Plain, the Piedmont, and the Appalachian Mountains and foothills. Mooresville and Charlotte are part of the Piedmont region. North Carolina contains several major cities, like Charlotte and Raleigh, but much of the state could be classified as suburban or rural. As of the 2010 Census, North Carolina was 69% white and 22% black, but Iredell county, which contains Mooresville, was 83% white and 12% black.

[12] These counties are Alexander, Catawba, Lincoln, Cabarrus, Rowan, and Davie.

[13] Iredell County also contains the Iredell-Statesville Schools district.

a control group. We also estimated the specifications testing for heterogeneity in program impacts using the restricted sample of Mooresville and neighboring counties. (Results available on request.) The estimated impacts were similar, but precision decreased to the point that some of the triple interaction terms were not statistically different from zero.

Given that we study medium-term impacts, there is concern that the test and control groups may be contaminated through transferring behavior. For example, high-achieving families may be more attracted to the laptop program. If this is the case, we would expect that high-achieving families are (1) less likely to move if they already reside in Mooresville, (2) more likely to move to Mooresville relative to surrounding areas, or (3) seek to transfer into Mooresville if they live in a nearby district. The first group of families is difficult to identify; however, we can study the students who are new to the Mooresville Graded School District. The student identifier created by the NCERDC follows students as they change schools and school districts. Thus, we can analyze the proportion of students that are new to the North Carolina public school system and the proportion of students transferring from other districts within the state system. We present the results of this analysis in Appendix Table A.4.

We find that overall transfers into the Mooresville Graded School District declined with the introduction of the Digital Conversion Initiative. In 2006-2007, 12% of Mooresville students were new to the North Carolina public school system, and 7% were transfers from another NC school district. Shortly after implementation, 6% were new to NC schools, and 4% were new to Mooresville from another NC district. However, transfers in the rest of North Carolina public schools also declined in the same time period. Families may have been less mobile in the aftermath of the 2008 financial crisis. We compare the mean difference-in-differences of several transfer variables and find that transferring behavior declined more in Mooresville than in the rest of the state. We also examine whether Mooresville received a higher number of transfers from nearby school districts after the implementation of the Digital Conversion Initiative. We consider transfers from the Charlotte-Mecklenburg area separately from other nearby school districts. Our results indicate that a lower proportion of Mooresville students were transfers from nearby districts shortly after implementation, but these proportions returned to near their normal levels in the medium term. One potential explanation is that families are wary of moving to a district that is making significant structural changes. Once the Digital Conversion Initiative was advertised as a success, families' concerns were smoothed over.

Even though we find that the proportion of transfer students decreased in Mooresville, we still examine whether our regression results are robust to dropping transfer students. These estimates are reported in the last two columns of Table 7. For the first sample, we condition on students attending the same school district in the previous year, or two years total. For the other, we condition on attending the same school district for the past three years. Since the EOG files start at 3rd grade, 4th grade students are automatically dropped from this second sample. In both cases, results are very similar to estimation with the full sample. Thus, transferring behavior does not seem to contaminate our results.

4.3 Results for behavioral outcomes

Information on student behavior may provide clues about the mechanisms through which the laptop program improved student achievement in the district. The NCERDC files contain data on student time use and days absent. The coverage of years for these behavioral variables is less comprehensive than the test score data. Specifically, time use data were not collected after 2011, and days absent was not reported after 2012. In contrast, the achievement results combine test score data for the years 2006-2013.

We first analyze whether the laptop program brought about changes to time spent using a computer at home for school work, time spent on homework, and time spent free reading. We present these results in the first three columns of Table 8 and in Figures 7, 8, and 9, respectively. We find that the laptop program did indeed increase the amount of time students spent using a computer at home. Relative to the base year of 2008, computer use increased by 9.5 days per month in the first full year of implementation. The mean reported computer use for the full sample was 3.1 days per month, so computer use for students exposed to the laptop program increased threefold relative to the state average. In the second year of full implementation, computer use further increased by 3 days. This additional increase could be due to teachers more fully integrating the laptops into their lesson plans and assigned homework. We take these results as evidence that the laptop program worked in the most basic sense of increasing student exposure to computers.

In contrast, the changes in homework time and free reading are less stark. Exposed students increased their time spent on homework per week by 6.5 minutes in 2010 and 2011 relative to the chosen base year. However, this result is somewhat sensitive to the choice of base year. The 6.5 minute impact for homework is also quite small relative to the average homework time of 2.4 hours per week. For time spent free reading, we find that the laptop program caused a slight decrease of about 5 minutes per day in the short term. This effect size is relatively larger compared to the sample average of 48 minutes per day. These results suggest that the laptop initiative induced students to spend more time on some educationally enriching activities, but less time on others. To the extent that free reading is more beneficial for reading achievement than math achievement, the decrease in time spent free reading could partly explain why the laptop program had a smaller impact on exposed students' reading scores.

While the time use survey was offered at the time of testing in all years, there is a higher rate of nonresponse in 2009-2011. We analyze whether Mooresville students had differentially higher nonresponse rates. Since nonresponse across time use outcomes is highly correlated (above 0.98 in all pairwise correlations), we define a single dummy variable that equals one when all time use outcomes are missing. We then estimate equation (1) with this variable as the outcome and report the results in the last column of Appendix Table A.2. For the rest of North Carolina, time use survey nonresponse was 15-18 percentage points higher in 2009-2011 relative to 2008. Mooresville students also had higher nonresponse rates in those years relative to 2008, but by 2-5 percentage points less than the rest of the state. The generally elevated level of time use nonresponse is concerning, but it is less of an issue in Mooresville. Still, we interpret the time use results with some caution.

Another mechanism through which the laptop program could improve student achievement is through a reduction in absenteeism. If students are more engaged at school, they are less likely to miss class. Aucejo and Romano (2016) show that reductions in absences lead to test score gains. The final column of Table 8 reports point estimates for the impact of the laptop program on absences; Figure 10 displays them graphically. We find some evidence that the laptop program reduced student absenteeism. The biggest reduction in absences occurred in 2009 and 2010, shortly after initial implementation; students on average missed 1.5 and 1.2 fewer days in those years, respectively. Absences in Mooresville in 2011 and 2012 were also lower than the chosen base year of 2008, but by a smaller margin. If we instead use 2007 as the base year, we would conclude that absences in 2011 were significantly higher ($p = 0.013$), while absences in 2012 were statistically no different ($p = 0.15$). Thus, our finding of reduced absences in later years is sensitive to the choice of the base year. The initial reduction in absences could be due to temporary excitement at the prospect of using laptops at school. When laptops became a normalized part of school and district culture, students may have reverted to their usual patterns of absenteeism.

5 Conclusion

One-to-one computing is a promising avenue to bring about positive changes in student outcomes. However, the desired effects may not appear until a few years after the transition. This paper highlights the need to follow outcomes into the medium and long term. Furthermore, the results presented here indicate that one-to-one initiatives can help close the achievement gap between minority and white students. Although technology programs are sometimes advertised as benefitting the tails of the ability distribution through customized lesson plans, we do not find conclusive evidence that students with prior scores in the upper and lower quartiles benefit more than the middle 50% of the distribution.

We find some evidence that the laptop program impacted student behavior. For instance, students reported spending more time on homework after implementation. This evidence suggests that changes to student behavior played a role in the laptop program's success. It is important to stress that this paper only analyzed a few of the many mechanisms through which the laptop program may have impacted test scores. Most notably, we did not consider a role for changes in teacher and parent behavior.[14] We leave these mechanisms for future work.

Also not considered here is a role for change in the district's culture. In writing about the Digital Conversion Initiative, the Mooresville Superintendent Mark Edwards emphasizes the concept of "second-order change." The first-order change was giving every student a laptop. Second-order change involves a deeper level of transformation. Edwards writes that digital conversion "supports second-order change by enabling a fundamental shift across all aspects of daily life in our schools. It affects instruction, pedagogy, professional development, student and teacher motivation, student-teacher roles, learning experiences, and relationships" (Edwards, 2013, p. 4). If culture change is indeed a key mechanism, the external validity of this study is called into question. We could not give a laptop to every student in a school district and expect the same changes in outcomes without also focusing on changing district culture.

Future work is also needed to determine whether one-to-one technology interventions are effective for students outside of grades 4-8. For example, students in lower grades may need to focus on skills not easily taught through computers. There may be more scope for a reduction in absenteeism in later grades. Compounding effects of the laptop program

[14] Fairlie and Robinson (2013) analyze whether program impacts vary by several measures of parental involvement and supervision, and find no evidence that they do. However, they also find a null treatment effect overall. Taylor (2015) finds that the variance in teacher productivity, as measured by student test scores, decreases with the introduction of computer-aided instruction software, and that this reduction comes in part from changes in teacher effort level and decisions about how to allocate class time.

could increase high school graduation rates. If the laptop program sparks greater interest in technology, another effect could be greater interest in STEM majors and careers, such as computer engineering. Early computer-based interventions could help eliminate gaps in female and minority interest in STEM majors.

A final, important consideration is whether one-to-one technology programs can pass a cost-benefit analysis. While the test score increases found here are quite large, providing every student with a laptop or tablet is costly. The Mooresville school district has received some outside funding, and a local broadband provider offers discounted rates to low-income families. The community also bears some costs by extending hours for city buildings so that students can have Wi-Fi access after school hours. Parents are charged a technology usage fee, although many school districts charge fees for textbooks and activities. However, the Mooresville district emphasizes that its operating budget covers 98% of the cost of the program. While some expenses increased, others, such as print textbooks and computer labs, were reduced or eliminated. Mooresville's experience suggests that other school districts can also adopt one-to-one technology programs by shifting spending. If these programs can be implemented in a cost-neutral way, even small test score gains provide enough benefit to justify the transition.

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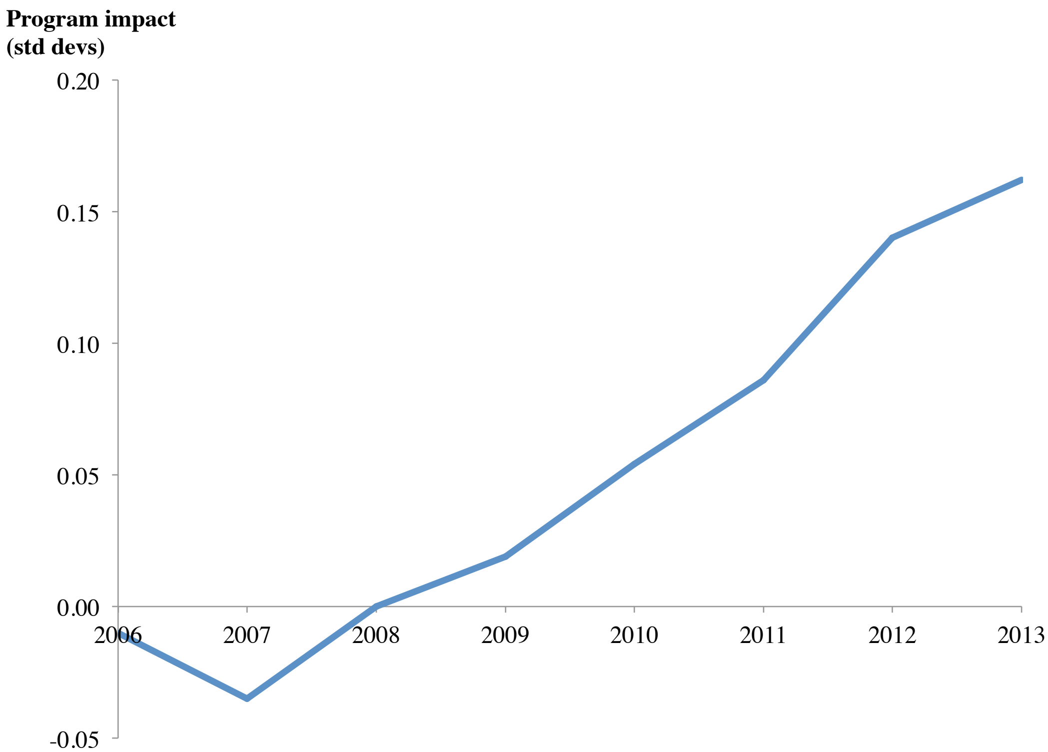
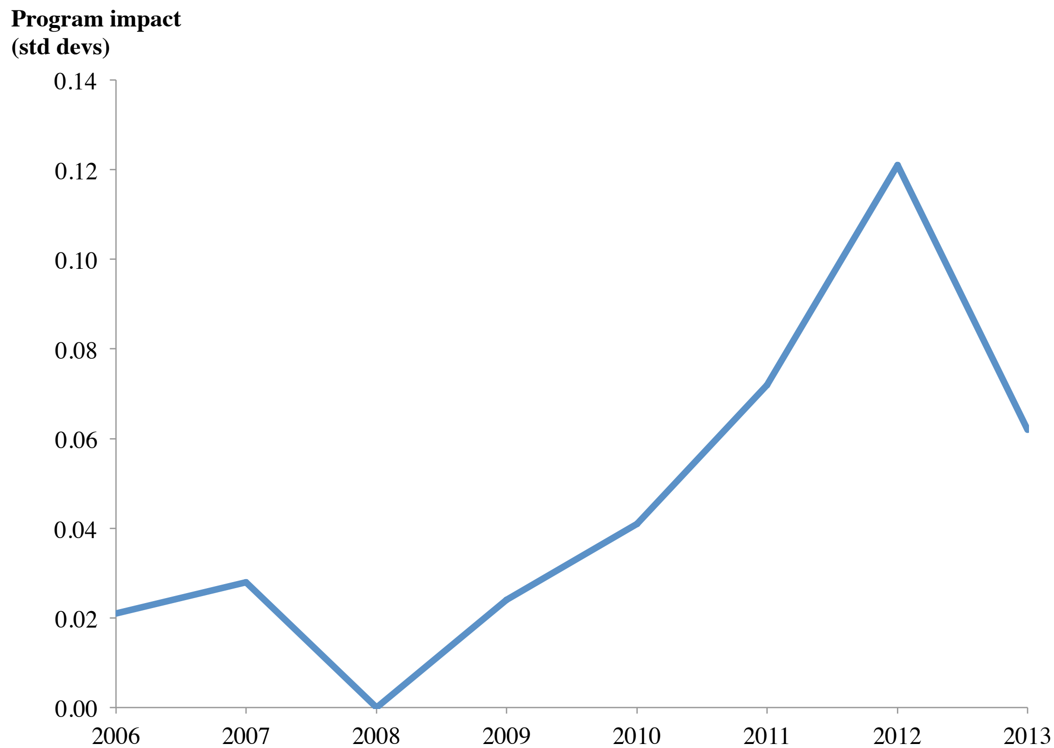
Figure 1: Program impacts for math scores



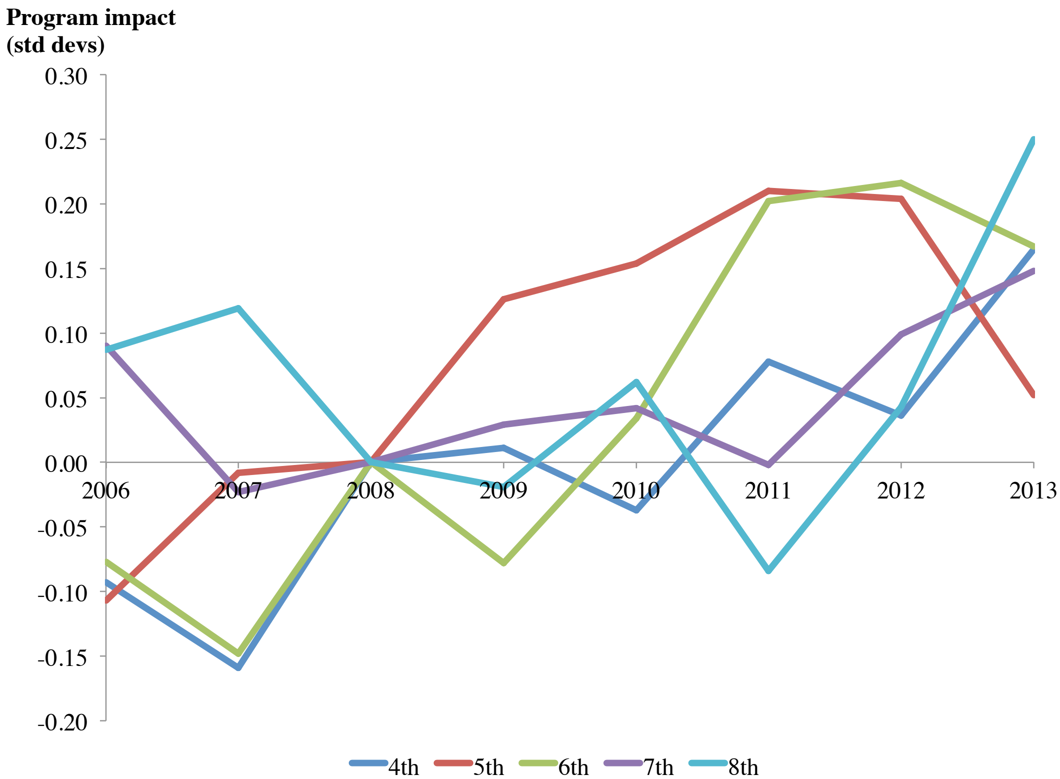
Notes: Estimates from Table 2.

Figure 2: Program impacts for reading scores



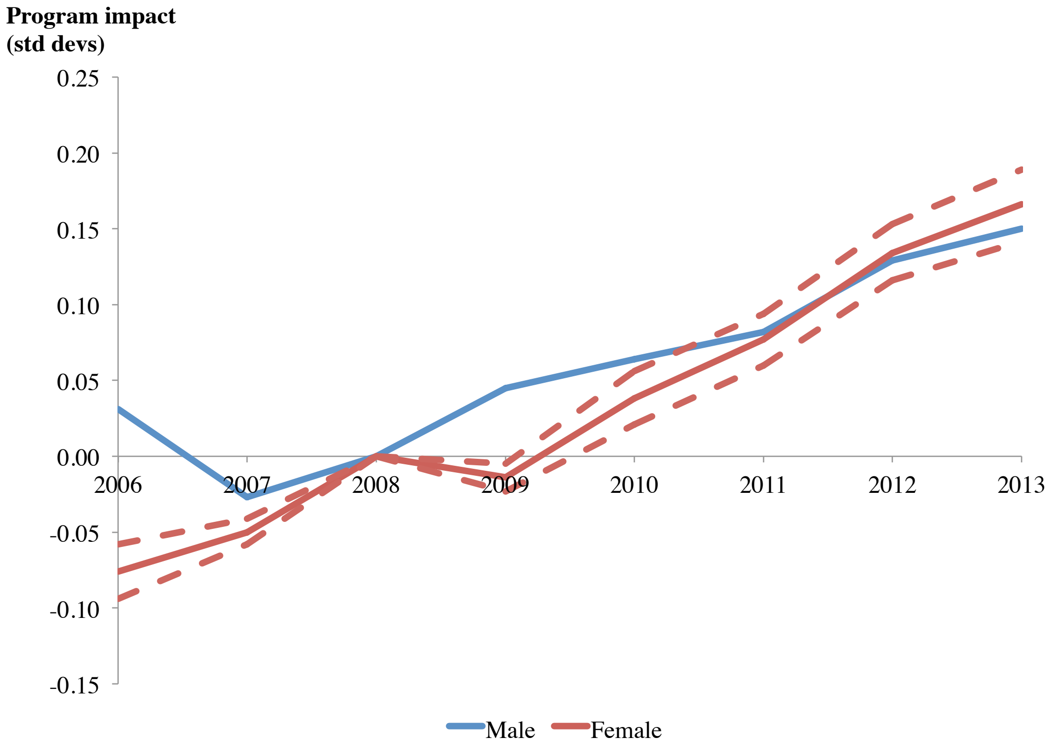
Notes: Estimates from Table 2.

Figure 3: Program impacts for math scores by grade



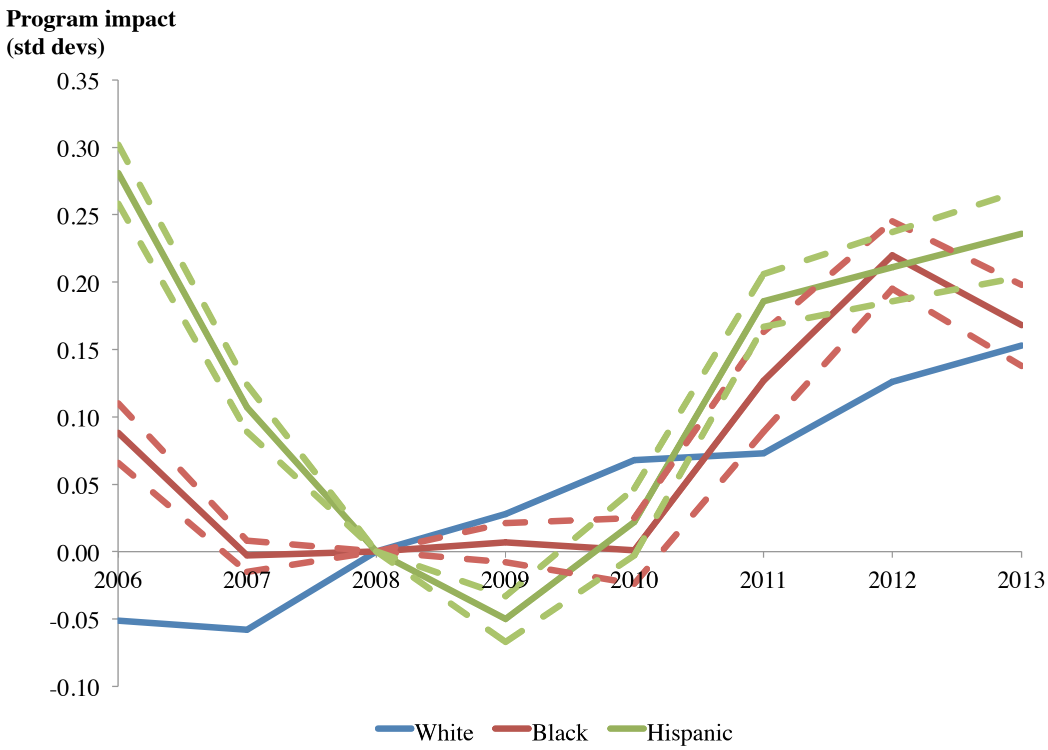
Notes: Estimates from Table 3.

Figure 4: Program impacts for math scores by gender



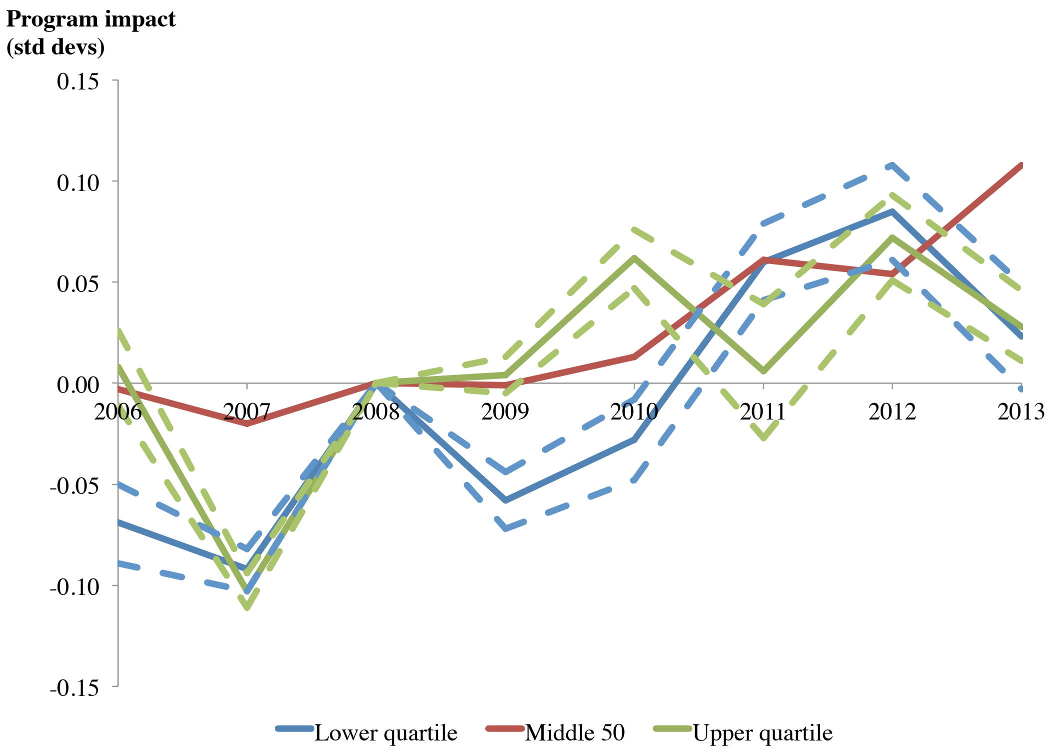
Notes: Estimates from Table 4. Dashed lines indicate 95% confidence intervals for the program impacts for female students.

Figure 5: Program impacts for math scores by ethnicity



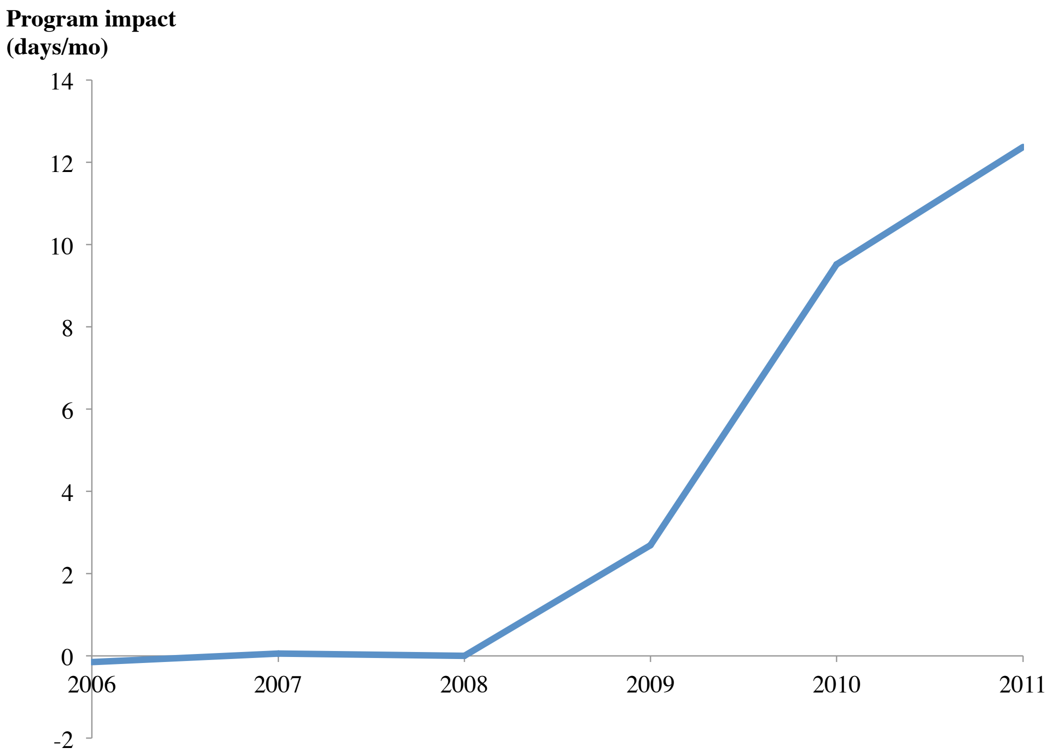
Notes: Estimates from Table 5. Dashed lines indicate 95% confidence intervals for the program impacts for black and Hispanic students.

Figure 6: Program impacts for math scores by prior score



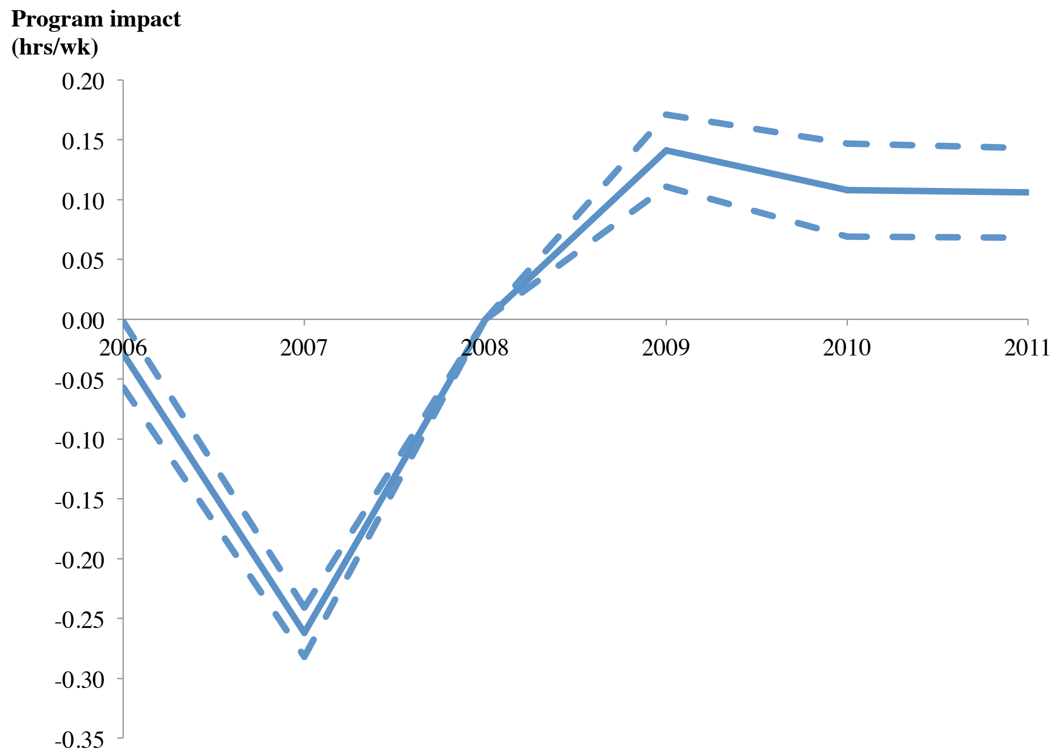
Notes: Estimates from Table 6. Dashed lines indicate 95% confidence intervals for the program impacts for students in the lower and upper quartiles of the prior score distribution (see text for details).

Figure 7: Program impacts for computer use



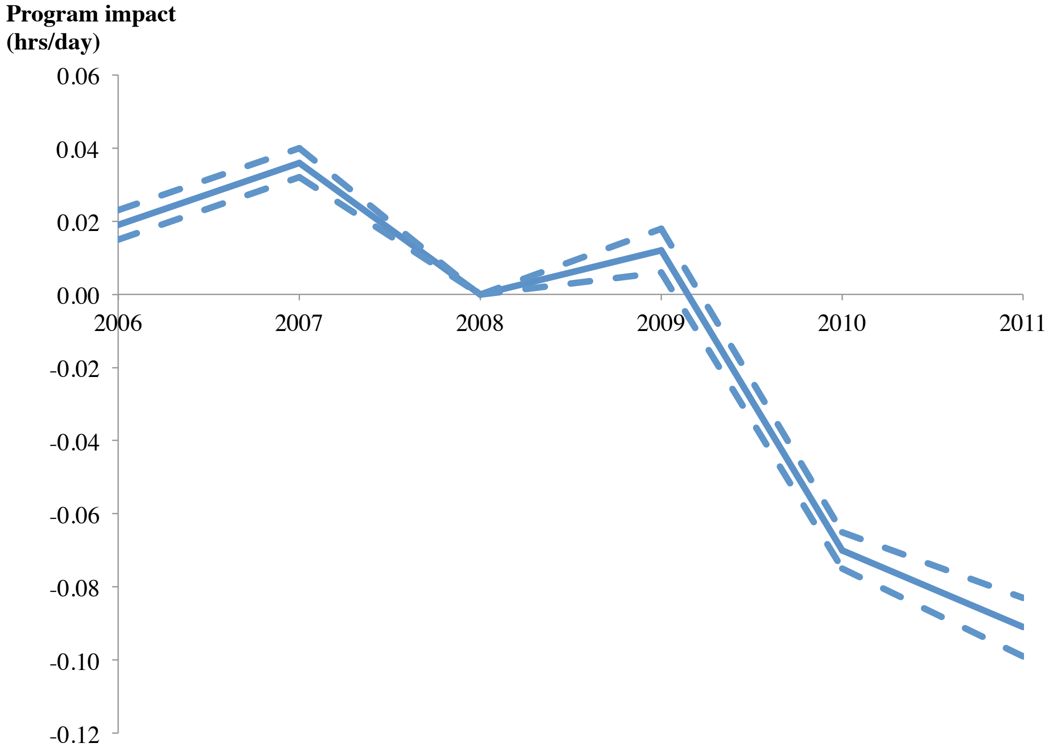
Notes: Estimates from Table 8.

Figure 8: Program impacts for homework time



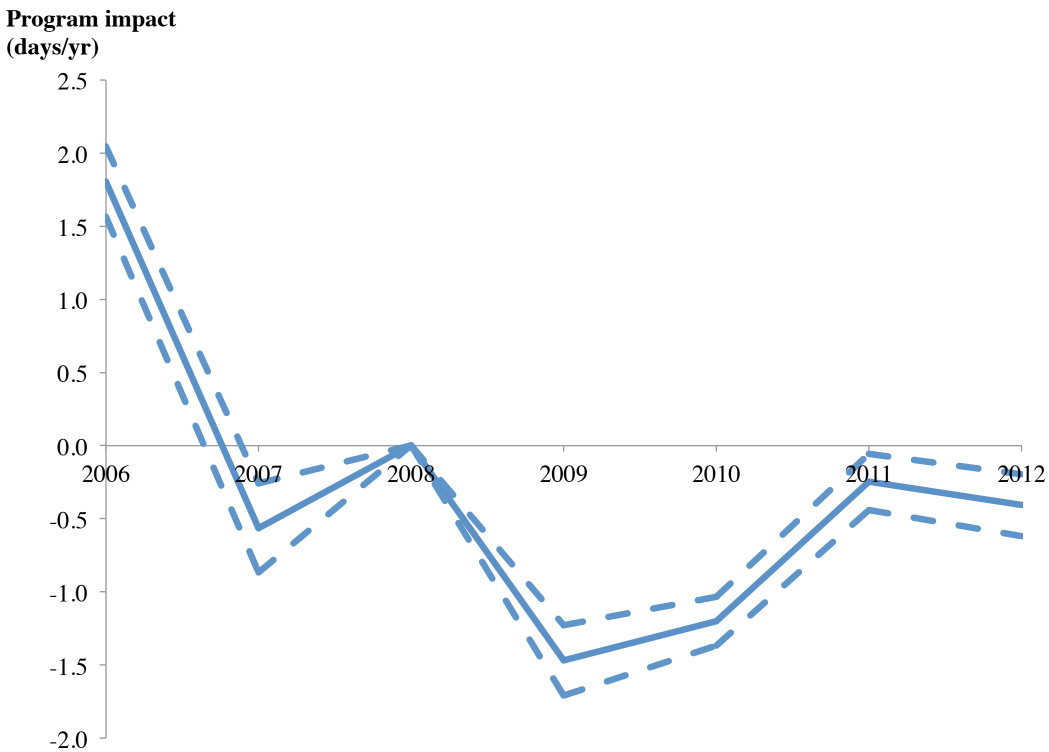
Notes: Estimates from Table 8. Dashed lines indicate 95% confidence intervals for the program impacts.

Figure 9: Program impacts for free reading



Notes: Estimates from Table 8. Dashed lines indicate 95% confidence intervals for the program impacts.

Figure 10: Program impacts for absences



Notes: Estimates from Table 8. Dashed lines indicate 95% confidence intervals for the program impacts.

Table 1: Mean student and school characteristics

	Rest of NC			Mooresville			Diff-in-diff	
	Pre	Short	Medium	Pre	Short	Medium	Short	Medium
Math score	-0.001	-0.001	-0.001	0.210	0.293	0.356	0.083***	0.147***
	(0.001)	(0.001)	(0.001)	(0.015)	(0.015)	(0.014)	(0.021)	(0.021)
Reading score	-0.001	-0.001	-0.001	0.195	0.216	0.234	0.021	0.039*
	(0.001)	(0.001)	(0.001)	(0.015)	(0.015)	(0.014)	(0.021)	(0.020)
White	0.561	0.542	0.525	0.771	0.745	0.731	-0.006	-0.004
Black	0.288	0.256	0.261	0.153	0.144	0.145	0.024***	0.020**
Hispanic	0.085	0.126	0.136	0.038	0.059	0.075	-0.020***	-0.015***
Multiracial	0.029	0.038	0.037	0.020	0.032	0.033	0.003	0.006
Asian	0.022	0.022	0.026	0.017	0.017	0.014	0.000	-0.007**
Am. Ind. or Pac. Is.	0.015	0.017	0.016	0.001	0.002	0.002	-0.001	-0.000
Female	0.483	0.490	0.490	0.499	0.479	0.493	-0.027**	-0.013
Age (mos)	150.5	149.5	149.6	150.2	148.6	149.1	-0.6	-0.2
	(0.0)	(0.0)	(0.0)	(0.3)	(0.3)	(0.3)	(0.4)	(0.4)
% subsidized lunch	0.454	0.514	0.546	0.310	0.402	0.384	0.033***	-0.017***
% white	0.566	0.536	0.523	0.775	0.745	0.735	0.001	0.003***
% black	0.304	0.282	0.258	0.165	0.161	0.144	0.017***	0.024***
% Hispanic	0.092	0.121	0.140	0.043	0.062	0.072	-0.010***	-0.018
Max observations	1,067,183	1,125,194	1,142,247	3,799	4,273	4,631		

Notes: Standard errors for the mean in parentheses. Baseline years are 2006 and 2007; short term is 2010 and 2011; and medium term is 2012 and 2013. Difference-in-differences are relative to the base years.
Key: Difference-in-difference relative to base years significant at the * 10% level, ** 5% level, or *** 1% level.

Table 2: Program impacts for test scores

Outcome:	Math score		Reading score	
Mooresville X 2006	-0.010	(0.002)	0.021	(0.002)
Mooresville X 2007	-0.035	(0.001)	0.028	(0.001)
Mooresville X 2009	0.019	(0.002)	0.024	(0.001)
Mooresville X 2010	0.054	(0.002)	0.041	(0.002)
Mooresville X 2011	0.086	(0.004)	0.072	(0.003)
Mooresville X 2012	0.140	(0.005)	0.121	(0.004)
Mooresville X 2013	0.162	(0.005)	0.062	(0.004)
Black	-0.652	(0.030)	-0.645	(0.025)
Hispanic	-0.414	(0.037)	-0.562	(0.033)
Multiracial	-0.272	(0.015)	-0.246	(0.012)
Asian	0.196	(0.037)	-0.126	(0.040)
Am. Ind. or Pac. Is.	-0.389	(0.028)	-0.405	(0.033)
Missing ethnicity	-0.267	(0.049)	-0.273	(0.050)
Female	-0.021	(0.005)	0.103	(0.005)
Age-for-grade (mos)	-0.031	(0.001)	-0.029	(0.001)
% subsidized lunch	-0.029	(0.015)	-0.016	(0.011)
% black	-0.444	(0.076)	-0.352	(0.059)
% Hispanic	-0.503	(0.114)	-0.489	(0.127)
% Asian	0.324	(0.205)	0.298	(0.175)
% Am. Ind. of Pac. Is.	-0.551	(0.243)	-0.270	(0.309)
% two or more races	-0.450	(0.124)	-0.275	(0.093)
Missing school characteristics	-0.312	(0.068)	-0.235	(0.071)
Constant	0.438	(0.038)	0.358	(0.036)
Observations	4,317,258		4,292,065	

Notes: Standard errors are in parentheses and clustered at the school district level. Regressions also control for school fixed effects.

Table 3: Program impacts for math scores by grade

Sample:	4th	5th	6th	7th	8th
Mooresville X 2006	-0.093	-0.107	-0.077	0.090	0.087
	(0.002)	(0.002)	(0.002)	(0.004)	(0.004)
Mooresville X 2007	-0.159	-0.008	-0.148	-0.023	0.119
	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
Mooresville X 2009	0.011	0.126	-0.078	0.029	-0.019
	(0.003)	(0.003)	(0.004)	(0.003)	(0.002)
Mooresville X 2010	-0.037	0.154	0.034	0.042	0.062
	(0.004)	(0.004)	(0.006)	(0.002)	(0.002)
Mooresville X 2011	0.078	0.210	0.202	-0.002	-0.084
	(0.007)	(0.007)	(0.005)	(0.007)	(0.008)
Mooresville X 2012	0.136	0.204	0.216	0.099	0.043
	(0.008)	(0.008)	(0.006)	(0.007)	(0.007)
Mooresville X 2013	0.165	0.052	0.167	0.148	0.250
	(0.008)	(0.008)	(0.006)	(0.005)	(0.006)
Observations	874,603	866,938	862,581	858,202	854,934

Notes: Standard errors are in parentheses and clustered at the school district level. Regressions also control for ethnicity, gender, age-for-grade, school ethnic composition, school proportion subsidized lunch, and school fixed effects.

Table 4: Program impacts for math scores by gender

Mooresville X 2006	0.031	(0.002)
Mooresville X 2007	-0.027	(0.001)
Mooresville X 2009	0.045	(0.002)
Mooresville X 2010	0.064	(0.002)
Mooresville X 2011	0.082	(0.004)
Mooresville X 2012	0.129	(0.004)
Mooresville X 2013	0.150	(0.004)
Mooresville X female	0.039	(0.006)
Mooresville X 2006 X female	-0.107	(0.009)
Mooresville X 2007 X female	-0.023	(0.004)
Mooresville X 2009 X female	-0.059	(0.005)
Mooresville X 2010 X female	-0.026	(0.009)
Mooresville X 2011 X female	-0.005	(0.008)
Mooresville X 2012 X female	0.005	(0.007)
Mooresville X 2013 X female	0.016	(0.011)
Observations	4,317,258	

Notes: Standard errors in parentheses and clustered at the school district level. Regressions also control for ethnicity, age-for-grade, school ethnic composition, school proportion subsidized lunch, and school fixed effects. Not reported are the double interactions of gender with year.

Table 5: Program impacts for math scores by ethnicity

Mooresville X 2006	-0.051	(0.002)
Mooresville X 2007	-0.058	(0.001)
Mooresville X 2009	0.028	(0.002)
Mooresville X 2010	0.068	(0.002)
Mooresville X 2011	0.073	(0.004)
Mooresville X 2012	0.126	(0.004)
Mooresville X 2013	0.153	(0.005)
Mooresville X black	-0.132	(0.033)
Mooresville X 2006 X black	0.139	(0.012)
Mooresville X 2007 X black	0.055	(0.006)
Mooresville X 2009 X black	-0.021	(0.007)
Mooresville X 2010 X black	-0.067	(0.013)
Mooresville X 2011 X black	0.054	(0.019)
Mooresville X 2012 X black	0.094	(0.012)
Mooresville X 2013 X black	0.015	(0.015)
Mooresville X Hispanic	-0.133	(0.043)
Mooresville X 2006 X Hispanic	0.332	(0.012)
Mooresville X 2007 X Hispanic	0.165	(0.009)
Mooresville X 2009 X Hispanic	-0.078	(0.009)
Mooresville X 2010 X Hispanic	-0.046	(0.013)
Mooresville X 2011 X Hispanic	0.113	(0.010)
Mooresville X 2012 X Hispanic	0.085	(0.013)
Mooresville X 2013 X Hispanic	0.083	(0.016)
Mooresville X multiracial	-0.063	(0.020)
Mooresville X 2006 X multiracial	-0.139	(0.014)
Mooresville X 2007 X multiracial	0.097	(0.008)
Mooresville X 2009 X multiracial	-0.101	(0.008)
Mooresville X 2010 X multiracial	-0.110	(0.011)
Mooresville X 2011 X multiracial	-0.135	(0.016)
Mooresville X 2012 X multiracial	-0.110	(0.014)
Mooresville X 2013 X multiracial	-0.116	(0.016)
Mooresville X Asian	0.006	(0.036)
Mooresville X 2006 X Asian	0.179	(0.024)
Mooresville X 2007 X Asian	0.099	(0.011)
Mooresville X 2009 X Asian	-0.088	(0.012)
Mooresville X 2010 X Asian	0.006	(0.015)
Mooresville X 2011 X Asian	-0.043	(0.037)
Mooresville X 2012 X Asian	-0.065	(0.022)
Mooresville X 2013 X Asian	0.338	(0.028)
Observations	4,317,258	

Notes: Standard errors in parentheses and clustered at the school district level. Regressions also control for gender, age-for-grade, school ethnic composition, school proportion subsidized lunch, and school fixed effects. Not reported are the double interactions of ethnicity with year and all sets of interactions for the group American Indian or Pacific Islander.

Table 6: Program impacts for math scores by prior performance

Mooresville X 2006	-0.003	(0.002)
Mooresville X 2007	-0.020	(0.001)
Mooresville X 2009	-0.001	(0.001)
Mooresville X 2010	0.013	(0.001)
Mooresville X 2011	0.061	(0.004)
Mooresville X 2012	0.054	(0.005)
Mooresville X 2013	0.108	(0.004)
Mooresville X 2006 X low prior score	-0.066	(0.009)
Mooresville X 2007 X low prior score	-0.072	(0.005)
Mooresville X 2009 X low prior score	-0.057	(0.007)
Mooresville X 2010 X low prior score	-0.041	(0.010)
Mooresville X 2011 X low prior score	-0.001	(0.010)
Mooresville X 2012 X low prior score	0.031	(0.011)
Mooresville X 2013 X low prior score	-0.085	(0.012)
Mooresville X low prior score	0.067	(0.011)
Mooresville X 2006 X high prior score	0.011	(0.009)
Mooresville X 2007 X high prior score	-0.083	(0.004)
Mooresville X 2009 X high prior score	0.005	(0.005)
Mooresville X 2010 X high prior score	0.049	(0.007)
Mooresville X 2011 X high prior score	-0.055	(0.015)
Mooresville X 2012 X high prior score	0.018	(0.009)
Mooresville X 2013 X high prior score	-0.080	(0.008)
Mooresville X high prior score	0.041	(0.007)
Mooresville X 2006 X missing prior score	0.113	(0.011)
Mooresville X 2007 X missing prior score	0.068	(0.011)
Mooresville X 2009 X missing prior score	0.029	(0.013)
Mooresville X 2010 X missing prior score	0.182	(0.016)
Mooresville X 2011 X missing prior score	-0.090	(0.014)
Mooresville X 2012 X missing prior score	0.131	(0.013)
Mooresville X 2013 X missing prior score	0.138	(0.017)
Mooresville X missing prior score	0.061	(0.020)
Observations	4,317,258	

Notes: Standard errors in parentheses and clustered at the school district level. Regressions also control for gender, ethnicity, age-for-grade, school ethnic composition, school proportion subsidized lunch, and school fixed effects. Not reported are the double interactions of prior performance with year.

Table 7: Program impacts for math scores, alternative samples

Sample:	Full	Neighboring counties	Same district, 2 years	Same district, 3 years
Mooresville X 2006	-0.010	-0.009	-0.008	0.017
	(0.002)	(0.005)	(0.002)	(0.002)
Mooresville X 2007	-0.035	-0.031	-0.029	-0.025
	(0.001)	(0.003)	(0.001)	(0.001)
Mooresville X 2009	0.019	0.032	0.018	-0.001
	(0.002)	(0.010)	(0.002)	(0.002)
Mooresville X 2010	0.054	0.076	0.064	0.068
	(0.002)	(0.015)	(0.002)	(0.002)
Mooresville X 2011	0.086	0.086	0.107	0.100
	(0.004)	(0.011)	(0.004)	(0.005)
Mooresville X 2012	0.140	0.149	0.149	0.140
	(0.005)	(0.014)	(0.005)	(0.005)
Mooresville X 2013	0.162	0.179	0.169	0.150
	(0.005)	(0.015)	(0.005)	(0.005)
Observations	4,317,258	393,333	3,904,842	2,854,699

Notes: Standard errors are in parentheses and clustered at the school district level. Regressions also control for gender, ethnicity, age-for-grade, school ethnic composition, school proportion subsidized lunch, and school fixed effects.

Table 8: Program impacts for time use and absences

Outcome	Computer use (days/mo)	Homework (hrs/wk)	Free reading (hrs/day)	Days absent (days/yr)
Mean	3.139	2.350	0.794	7.049
Mooresville X 2006	-0.154	-0.029	0.019	1.806
	(0.033)	(0.014)	(0.002)	(0.122)
Mooresville X 2007	0.063	-0.262	0.036	-0.563
	(0.026)	(0.010)	(0.002)	(0.154)
Mooresville X 2009	2.695	0.141	0.012	-1.469
	(0.054)	(0.015)	(0.003)	(0.122)
Mooresville X 2010	9.512	0.108	-0.070	-1.200
	(0.091)	(0.020)	(0.002)	(0.085)
Mooresville X 2011	12.371	0.106	-0.091	-0.247
	(0.132)	(0.019)	(0.004)	(0.098)
Mooresville X 2012				-0.407
				(0.108)
Observations	2,848,970	2,853,033	2,847,497	3,857,549

Notes: Standard errors are in parentheses and clustered at the school district level. Regressions also control for ethnicity, gender, age-for-grade, school ethnic composition, school proportion subsidized lunch, grade fixed effects, year fixed effects, and school fixed effects.

Appendix

Table A.1: Conversion of time use categories to continuous values

Response[a]	Relative frequency	Assigned value
Student uses computer at home		*days/mo*
I use a computer at home for school work almost every day	0.066	24
Once or twice a week	0.188	6
Once or twice a month	0.172	1.5
Hardly ever	0.336	0.5
Never, even though there is a computer at home	0.145	0
There is no computer at home	0.093	0
Time on homework		*hrs/wk*
No homework is ever assigned	0.015	0
Less than one hour each week	0.332	0.5
Between 1 and 3 hours	0.398	2
More than 3 but less than 5 hours	0.144	4
Between 5 and 10 hours	0.084	7.5
More than 10 hours	0.015	12
Has homework, but does not do it	0.011	0
Amount of time spent free reading		*hrs/day*
None	0.131	0
About 30 minutes	0.485	0.5
About 1 hour	0.197	1
Between 1 and 2 hours	0.114	1.5
More than 2 hours	0.074	2.5

[a] Variable titles and labels as they appear in the codebook.

Table A.2: Program impacts for missing outcomes

Outcome	Math score missing	Reading score missing	Time use missing
Mean	0.030	0.036	0.136
Mooresville X 2006	-0.011	-0.019	0.012
	(0.002)	(0.002)	(0.003)
Mooresville X 2007	0.005	0.002	0.005
	(0.001)	(0.001)	(0.003)
Mooresville X 2009	0.007	0.008	-0.020
	(0.003)	(0.003)	(0.005)
Mooresville X 2010	0.012	0.011	-0.046
	(0.003)	(0.003)	(0.005)
Mooresville X 2011	0.019	0.022	-0.028
	(0.002)	(0.002)	(0.004)
Mooresville X 2012	-0.002	0.000	
	(0.003)	(0.003)	
Mooresville X 2013	-0.005	-0.008	
	(0.003)	(0.003)	
Black	0.016	0.017	0.078
	(0.002)	(0.002)	(0.004)
Hispanic	0.007	0.018	0.063
	(0.001)	(0.002)	(0.003)
Multiracial	0.003	0.003	0.031
	(0.001)	(0.001)	(0.002)
Asian	0.003	0.020	0.011
	(0.002)	(0.004)	(0.004)
Am. Ind. or Pac. Is.	0.011	0.014	0.049
	(0.003)	(0.003)	(0.005)
Missing ethnicity	0.005	0.006	0.035
	(0.004)	(0.004)	(0.013)
Female	-0.011	-0.015	-0.014
	(0.001)	(0.001)	(0.001)
Age-for-grade (mos)	0.004	0.004	0.005
	(0.000)	(0.000)	(0.000)
% subsidized lunch	0.002	0.003	0.010
	(0.003)	(0.003)	(0.010)
% black	-0.018	-0.013	-0.220
	(0.010)	(0.010)	(0.036)
% Hispanic	-0.006	0.005	0.160
	(0.015)	(0.016)	(0.057)
% Asian	-0.035	-0.023	-0.677
	(0.027)	(0.025)	(0.124)

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Table A.2 – continued from previous page

Outcome	Math score missing	Reading score missing	Time use missing
% Am. Ind. of Pac. Is.	0.010	0.055	0.078
	(0.025)	(0.029)	(0.305)
% two or more races	0.086	0.104	-0.194
	(0.047)	(0.044)	(0.075)
Missing school chars	-0.020	-0.017	-0.120
	(0.009)	(0.009)	(0.042)
Grade 5	0.002	0.002	0.020
	(0.000)	(0.000)	(0.001)
Grade 6	0.003	0.001	-0.011
	(0.001)	(0.001)	(0.002)
Grade 7	0.002	0.000	0.003
	(0.001)	(0.001)	(0.003)
Grade 8	0.002	-0.001	0.010
	(0.001)	(0.001)	(0.003)
2006	-0.033	-0.031	-0.054
	(0.002)	(0.002)	(0.003)
2007	-0.003	-0.003	-0.038
	(0.001)	(0.001)	(0.003)
2009	-0.001	-0.000	0.180
	(0.003)	(0.003)	(0.005)
2010	-0.003	0.000	0.164
	(0.003)	(0.003)	(0.005)
2011	-0.006	-0.003	0.151
	(0.003)	(0.003)	(0.006)
2012	-0.005	-0.001	
	(0.004)	(0.003)	
2013	-0.011	-0.007	
	(0.003)	(0.003)	
Constant	0.040	0.041	0.099
	(0.004)	(0.004)	(0.019)
Observations	4,450,633	4,450,633	3,304,179

Notes: Standard errors in parentheses and clustered at the school district level. Regressions also control for school fixed effects.

Table A.3: Mean student and school characteristics, neighboring counties comparison

	Neighboring counties[a]			Mooresville			Diff-in-diff	
	Pre	Short	Medium	Pre	Short	Medium	Short	Medium
Math score	0.062	0.050	0.032	0.210	0.293	0.356	0.095***	0.176***
	(0.003)	(0.003)	(0.003)	(0.015)	(0.015)	(0.014)	(0.022)	(0.021)
Reading score	0.051	0.049	0.023	0.195	0.216	0.234	0.021	0.066***
	(0.003)	(0.003)	(0.003)	(0.015)	(0.015)	(0.014)	(0.021)	(0.021)
White	0.715	0.689	0.673	0.771	0.745	0.731	0.000	0.002
Black	0.139	0.136	0.137	0.153	0.144	0.145	-0.006	-0.006
Hispanic	0.087	0.111	0.128	0.038	0.059	0.075	-0.002	-0.004
Multiracial	0.030	0.036	0.033	0.020	0.032	0.033	0.006*	0.010***
Asian	0.027	0.026	0.026	0.017	0.017	0.014	0.001	-0.002
Am. Ind. or Pac. Is.	0.002	0.003	0.003	0.001	0.002	0.002	0.001	0.001
Female	0.485	0.489	0.487	0.499	0.479	0.493	-0.023**	-0.007
Age (mos)	150.2	149.2	149.4	150.2	148.6	149.1	-0.7*	-0.3
	(0.1)	(0.1)	(0.1)	(0.3)	(0.3)	(0.3)	(0.4)	(0.4)
% subsidized lunch	0.394	0.468	0.499	0.310	0.402	0.384	0.019***	-0.030***
% white	0.722	0.683	0.671	0.775	0.745	0.735	0.009***	0.011***
% black	0.155	0.154	0.135	0.165	0.161	0.144	-0.003***	-0.001
% Hispanic	0.093	0.115	0.129	0.043	0.062	0.072	-0.003***	-0.006***
Max observations	93,091	98,777	100,187	3,799	4,273	4,631		

Notes: Standard errors for the mean in parentheses. Baseline years are 2006 and 2007; short term is 2010 and 2011; and medium term is 2012 and 2013. Difference-in-differences are relative to the base years.

Key: Difference-in-difference relative to base years significant at the * 10% level, ** 5% level, or *** 1% level.

[a] Includes students in Alexander, Catawba, Lincoln, Cabarrus, Rowan, and Davie Counties as well as students in Iredell County who do not attend school in the Mooresville Graded School District.

Table A.4: Mean student transfer behavior

	Rest of NC			Mooresville			Diff-in-diff	
	Pre	Short	Medium	Pre	Short	Medium	Short	Medium
Transfer into NC public schools	0.077	0.060	0.050	0.115	0.061	0.061	-0.038***	-0.027***
	(0.000)	(0.000)	(0.000)	(0.005)	(0.004)	(0.004)	(0.006)	(0.006)
Transfer from different district within NC	0.041	0.031	0.039	0.072	0.040	0.062	-0.022***	-0.008
	(0.000)	(0.000)	(0.000)	(0.004)	(0.003)	(0.004)	(0.005)	(0.006)
Transfer from district near Mooresville[a]	0.002	0.001	0.002	0.042	0.031	0.040	-0.011**	-0.002
	(0.000)	(0.000)	(0.000)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
Transfer from Charlotte-Mecklenburg[b]	0.003	0.000	0.002	0.018	0.001	0.013	-0.015***	-0.005*
	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.002)	(0.002)	(0.003)
Max observations	1,067,183	1,125,194	1,142,247	3,799	4,273	4,631		

Notes: Standard errors for the mean in parentheses. Baseline years are 2006 and 2007; short term is 2010 and 2011; and medium term is 2012 and 2013. Difference-in-differences are relative to the base years.

Key: Difference-in-difference relative to base years significant at the * 10% level, ** 5% level, or *** 1% level.

[a] Districts near Mooresville include all school districts in Alexander, Catawba, Iredell (except Mooresville), Lincoln, Cabarrus, Rowan, and Davie Counties. Students attending school in one of these districts are not counted as transfers and are thus excluded from this calculation.

[b] Students attending school in Mecklenburg County are not counted as transfers and are thus excluded from this calculation.