Cognitive Skills, Student Achievement Tests, and Schools

Amy S. Finn, Matthew A. Kraft, Martin R. West, Julia A. Leonard, Crystal E. Bish, Rebecca E. Martin, Margaret A. Sheridan, Christopher F. O. Gabrieli and John D. E. Gabrieli

Psychological Science 2014 25: 736 originally published online 16 January 2014
DOI: 10.1177/0956797613516008

Research Article

Psychological Science
2014, Vol. 25(3) 736–744

DOI: 10.1177/0956797613516008
pss.sagepub.com

Cognitive Skills, Student Achievement Tests, and Schools

Amy S. Finn[1,2,3], Matthew A. Kraft[4], Martin R. West[5], Julia A. Leonard[1,2], Crystal E. Bish[6], Rebecca E. Martin[1,2,7], Margaret A. Sheridan[3], Christopher F. O. Gabrieli[5,6], and John D. E. Gabrieli[1,2,5]

[1]Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology; [2]McGovern Institute for Brain Research, Massachusetts Institute of Technology; [3]Department of Developmental Medicine, Boston Children's Hospital, Boston, Massachusetts; [4]Department of Education, Brown University; [5]Harvard Graduate School of Education, Harvard University; [6]Transforming Education/National Center on Time and Learning, Boston, Massachusetts; and [7]Department of Psychology, Columbia University

Abstract

Cognitive skills predict academic performance, so schools that improve academic performance might also improve cognitive skills. To investigate the impact schools have on both academic performance and cognitive skills, we related standardized achievement-test scores to measures of cognitive skills in a large sample (N = 1,367) of eighth-grade students attending traditional, exam, and charter public schools. Test scores and gains in test scores over time correlated with measures of cognitive skills. Despite wide variation in test scores across schools, differences in cognitive skills across schools were negligible after we controlled for fourth-grade test scores. Random offers of enrollment to oversubscribed charter schools resulted in positive impacts of such school attendance on math achievement but had no impact on cognitive skills. These findings suggest that schools that improve standardized achievement-test scores do so primarily through channels other than improving cognitive skills.

Keywords

adolescent development, childhood development, cognition, cognitive development, educational psychology

Received 2/8/13; Revision accepted 11/6/13

A fundamental goal of education is to equip students with the knowledge and skills necessary to think critically, solve complex problems, and succeed in the 21st-century society and economy. Measurement of such knowledge and skills is essential to tracking students' development and assessing the effectiveness of educational policies and practices. Education and psychological science have examined these issues in nearly complete separation. Education researchers have used many measures of learning, but recent research has drawn primarily on standardized achievement tests designed to assess students' mastery of state-defined content standards in core academic subjects (Borman, Hewes, Overman, & Brown, 2003; Hanushek & Rivkin, 2010). Psychological science has used measures of several cognitive concepts to assess variation in domain-independent mental skills, including processing speed (how efficiently information can be processed; Kail & Salthouse, 1994), working memory capacity (how much information can be simultaneously processed and maintained in mind; Cowan, 2005; Gathercole, Pickering, Knight, & Stegmann, 2004), and fluid reasoning (how well novel problems can be solved; also termed general fluid intelligence, or fluid g; Engle, Tuholski, Laughlin, & Conway, 1999). In the present study, we integrated these two approaches to measuring knowledge and skills by asking how the enhancement of

Corresponding Author:
Amy S. Finn, Massachusetts Institute of Technology, Department of Brain and Cognitive Sciences, 43 Vassar St., Building 46-4037, Cambridge, MA 02139
E-mail: amyfinn@mit.edu

academic performance by schools relates to the types of cognitive skills studied in psychological science.

Studies of cognitive development have focused on processing speed, working memory capacity, and fluid reasoning as three interrelated cognitive abilities that develop markedly from childhood through adulthood and that predict individual differences in performance on numerous measures (Cowan et al., 2005). Studies from late childhood through young adulthood indicate that gains in processing speed support gains in working memory capacity that, in turn, support gains in fluid reasoning (Coyle, Pillow, Snyder, & Kochunov, 2011; Fry & Hale, 1996; Kail, 2007).

These maturing mental abilities are thought to broadly underpin learning and cognitive skills. Variation in these measures predicts performance on a wide range of tasks among adults, including comprehension (Daneman & Carpenter, 1980), following directions, learning vocabulary, solving problems, and taking notes (Engle, Kane, & Tuholski, 1999). Critically, these cognitive abilities are associated with academic performance. Executive function measured in preschool predicts performance on math and literacy in kindergarten (Blair & Razza, 2007), and parental reports of attention span in 4-year-olds predict college completion at age 25 (McClelland, Acock, Piccinin, Rhea, & Stallings, 2013). Likewise, working memory skill correlates with math and reading ability among 5- and 6-year-olds (Alloway & Alloway, 2010) and among 11- and 12-year-olds (St Clair-Thompson & Gathercole, 2006), and it also predicts mathematics and science achievement among adolescents (Gathercole et al., 2004). Thus, cognitive skills appear to promote or constrain learning in school.

Although cognitive skills are seldom taught explicitly in schools, research indicates that schooling can promote cognitive skills in children. Using age cutoffs that determine the age at which young children are enrolled in schools, studies have shown that attending (vs. not attending) school for a year (Burrage et al., 2008) or attending school for more years (McCrea, Mueller, & Parrila, 1999) was associated with better performance on tests of working memory and executive functions. Reviews of the empirical literature examining the relationship between schooling attainment and IQ reveal a consistent positive relationship between time spent in school and measures of intelligence (Ceci, 1991; Ceci & Williams, 1997). These observational studies suggest that school attendance can improve cognitive skills beyond what is taught directly.

What is unknown but crucial for informing educational policy is whether general educational practices that increase academic performance also have a positive impact on basic cognitive skills. Schools traditionally focus on teaching knowledge and skills in content areas, such as mathematics and language arts. Use of such knowledge can be referred to as *crystallized* intelligence (Cattell, 1967). In contrast, *fluid* intelligence refers to the ability to solve novel problems largely independently of acquired knowledge; the cognitive measures in the present study are indices of fluid intelligence. Do schools where students are experiencing high levels of academic success in crystallized intelligence achieve this success by promoting the growth of fluid cognitive abilities? The strong relation between cognitive ability and academic performance suggests that schools that are particularly effective in improving academic performance may also improve domain-independent cognitive skills.

To shed light on this issue, we examined the relations between scores on standardized tests in mathematics and English language arts (ELA) on the Massachusetts Comprehensive Assessment System (MCAS; Massachusetts Department of Elementary & Secondary Education, 2011) and measures of cognitive skills among 1,367 eighth graders attending traditional district schools, exam schools (i.e., those that only accept students who pass specific exams), and charter public schools in a large urban school district. First, we asked whether there was an association among eighth-grade MCAS scores, gains in MCAS scores between fourth and eighth grade, and cognitive skills. Second, we compared the share of the overall variance in MCAS scores and cognitive skills explained by the school attended in eighth grade. Finally, we asked whether attending one of five oversubscribed charter schools that select students randomly by lottery and that generate consistent achievement gains on the MCAS (Abdulkadiroglu, Angrist, Dynarski, Kane, & Pathak, 2011; Angrist, Cohodes, Dynarski, Pathak, & Walters, 2013) also led to similar gains in cognitive skills.

Method

Participants

From among 1,852 eighth-grade participants, results are reported for 1,367 students for whom there were test-score data from both fourth and eighth grades (47% male, 53% female; 77% free-lunch eligible; 41% African American, 36% Hispanic, 12% White (non-Hispanic), 11% other race or ethnicity; for further demographic information, see Table S1 and Participants in the Supplemental Material available online).

Apparatus, stimuli, and tasks

Participants were tested in groups in classrooms, and they recorded responses in booklets. Stimuli were presented on a projector. Students completed the tasks, all of which were adapted for group classroom administration, in the order presented as follows with a proctor, an additional experimenter, and a teacher present. (See the Supplemental Material for more detail about the tasks and data collection.)

Processing speed. To evaluate students' processing speed, we used the Coding and Symbol Search subtests from the fourth edition of the Wechsler Intelligence Scale for Children (Wechsler, 2003). On the Coding subtest, students are asked to translate digits into symbols by referring to a corresponding digit-symbol key (nine novel symbols corresponded to the digits 1 through 9). On the Symbol Search subtest, students indicate whether either of two symbols on the left side of a page matches any of five symbols on the right side of a page. Students had 2 min to complete each task.

Working memory. Working memory was assessed with a count span task (Case, Kurland, & Goldberg, 1982; Cowan et al., 2005), in which students viewed an array with blue circles, blue triangles, and red circles and were instructed to count only the blue circles (targets) within 4.5 s. After one or more arrays were presented, students were prompted to write separately the number of targets presented in each display. Load ranged from 1 to 6 consecutive arrays and increased by one after three instances of a particular load.

Fluid reasoning. Fluid-reasoning ability was assessed using the fourth edition of the Test of Nonverbal Intelligence (Version A; Brown, Sherbenou, Johnsen, 2010). Students chose which of six pictures completed the missing piece of a puzzle. Choosing the correct response required the integration of progressively more difficult information (such as shape, pattern, and orientation). Students completed as many of 40 puzzles as possible in 10 min. (See the Fig. S2 and Validation in the Supplemental Material for information about validation.)

Procedure

Composite cognitive measure. Because the three measures of cognitive skills were moderately correlated (rs ranged from .23 to .32, $p < .001$), we combined them into a composite reflecting general cognitive ability with greater breadth and reduced measurement error. To calculate the composite score, we standardized each measure to have a mean of 0 and variance of 1, and then we averaged these standardized scores.

MCAS scores and charter lottery status. We obtained school enrollment and demographic information and MCAS math and ELA scores from databases maintained by the Massachusetts Department of Elementary and Secondary Education. MCAS scores were standardized to have a mean of 0 and variance of 1 by grade, subject, and year across all tested students in Massachusetts. Data from the lotteries used to admit participating students were acquired directly from the charter schools. Lottery records were matched to state administrative data using name, year, and grade at time of application, which yielded a total of 702 verified lottery participants (winners: n = 481, losers: n = 221; see Fig. S1 in the Supplemental Material).

Results

Representativeness of the sample

To examine how representative participating students were of public school students in the school district, we compared the fourth- and eighth-grade MCAS scores for students in our sample with those of all tested students in the school district (Fig. S1 in the Supplemental Material). The same comparisons were made separately for traditional, exam, and charter schools (Fig. 1). The study sample was generally representative of the student population in the district public schools, although participating students in traditional schools scored slightly higher than their nonparticipating peers on the eighth-grade math and ELA MCAS. Exam-school students scored highest, which is unsurprising considering that their admission to those schools was based on test performance. Notably, students admitted to charter schools via random lotteries moved from below to well above the statewide average between fourth and eighth grade.

Relations of MCAS scores to cognitive measures

We examined the relations between MCAS scores and processing speed, working memory, fluid reasoning, and the composite measure. Bivariate Pearson correlations revealed significant and positive relations between math scores and cognitive measures—processing speed: r = .46, $p < .001$; working memory: r = .27, $p < .001$; fluid reasoning: r = .53, $p < .001$; composite: r = .57, $p < .001$—and also between ELA scores and cognitive measures—processing speed: r = .38, $p < .001$; working memory: r = .18, $p < .001$; fluid reasoning: r = .36, $p < .001$; composite: r = .40, $p < .001$.

Relations of gains in MCAS scores to cognitive measures

To explore the relations between cognitive measures and MCAS scores collected in fourth and eighth grades (independent of one another), we conducted a path analysis

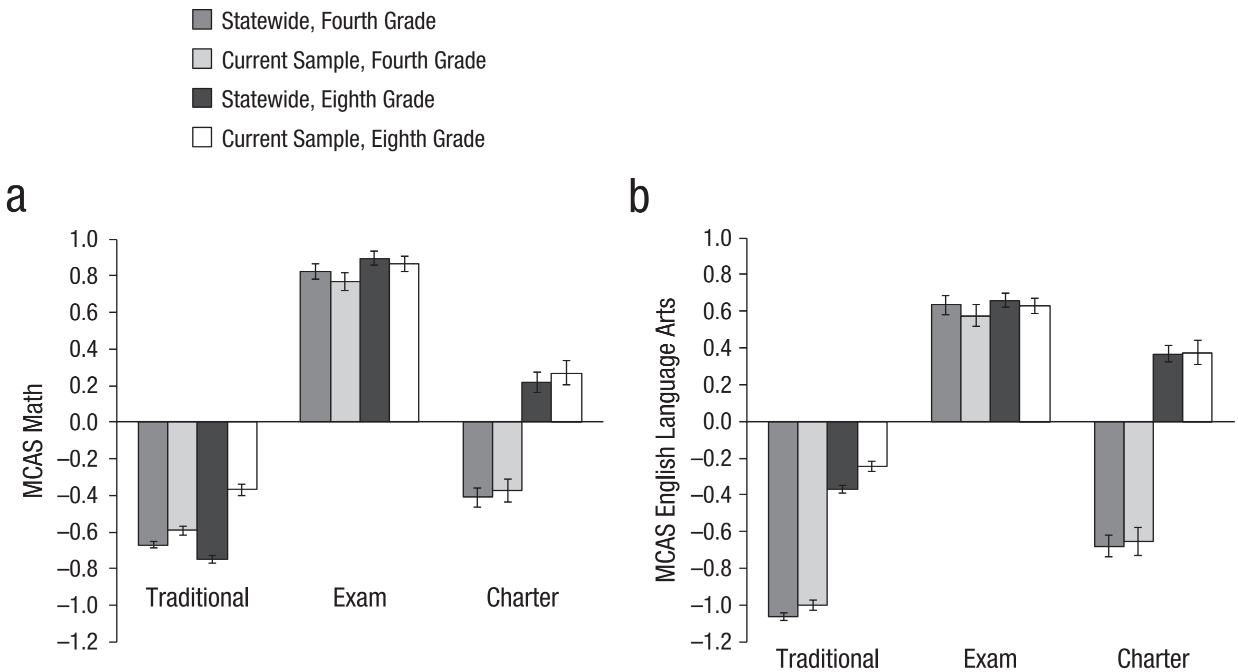

Fig. 1. Mean score for (a) math and (b) English language arts on the Massachusetts Comprehensive Assessment System (MCAS) as a function of school type and student group. Scores are graphed separately for all tested students in Massachusetts and in the current study sample only at the fourth- and eighth-grade levels. MCAS scores were standardized by subject, grade, and year to have a mean of 0 and variance of 1 in the population of students attending Massachusetts public schools. Error bars represent ±1 *SEM*.

(Fig. S3 in the Supplemental Material). For both math and ELA, we found positive and statistically significant relations between both fourth- and eighth-grade test scores and each cognitive measure. Measures of cognitive ability could be correlated with eighth-grade achievement independent of fourth-grade achievement because, among other factors, (a) assessments administered contemporaneously in eighth grade are more related to one another than to an assessment administered in fourth grade, and (b) the eighth-grade tests assessed more cognitively complex topics than the fourth-grade tests did.

To provide additional evidence that improvement on MCAS tests was related to cognitive performance, we calculated achievement gains for each student as the difference between students' eighth-grade test scores and their predicted scores based on a multivariate model with cubic functions of fourth-grade student achievement in both math and ELA. These gains correlated positively with cognitive measures, with stronger correlations in math (processing speed: $r = .29$, $p < .001$; working memory: $r = .12$, $p = .001$; fluid reasoning: $r = .32$, $p < .001$; composite: $r = .32$, $p < .001$) than in ELA (processing speed: $r = .21$, $p < .001$; working memory: $r = .04$, $p = .2$; fluid reasoning: $r = .19$, $p < .001$; composite: $r = .18$, $p < .001$). These findings suggest that overall academic improvement, which here includes any gains attributable to the school attended and to other individual and contextual factors, was related to cognitive ability.

Relations of schools to MCAS scores and cognitive measures

To probe the impact of which school a child attended on each of these measures, we first asked how much of the observed variance in each of the eighth-grade MCAS test scores and each of the cognitive measures can be explained by which school a student attended. Specifically, we decomposed the total variation in MCAS and cognitive scores into variation in the average scores—separately for each test (math and ELA) and cognitive measure (processing speed, working memory, fluid reasoning, and composite)—between the 32 schools in our sample and variation in the scores of individual students within each of these schools. These analyses of variance controlled for fourth-grade MCAS scores and demographics (gender, race, age, free- and reduced-priced-lunch status, limited English proficiency, and special-education status). Which school a child attended explained between 24% (ELA) and 34% (math) of variation in eighth-grade MCAS scores in our sample (conditional on fourth-grade achievement) but less than 7% of variation in processing speed, less than 2% for working memory and fluid reasoning, and less than 3% of the composite cognitive construct (Fig. 2a).

This pattern of large variation in achievement but minimal variation in cognitive measures across schools was also observed when we performed these same analyses

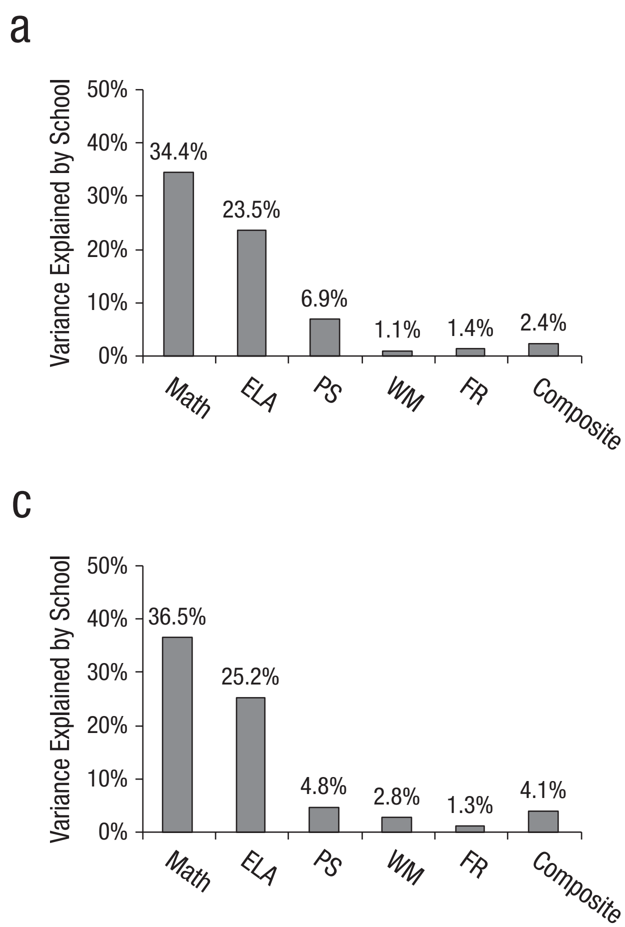

Fig. 2. Variance explained by which school students attended as a function of eighth-grade Massachusetts Comprehensive Assessment System (MCAS) scores on tests of math and English language ability (ELA) as well as cognitive measures of processing speed (PS), working memory (WM), fluid reasoning (FR), and a composite cognitive measure. The percentage of school-level variance for each outcome was calculated using analyses of variance controlling for four sets of factors. Variance when controlling for student demographics and fourth-grade MCAS scores across all measures is shown in (a). The graph in (b) shows variance when controlling for demographics and fourth-grade MCAS scores for all outcomes and the composite cognitive measure for test scores and eighth-grade MCAS scores for cognitive measures. Variance when controlling for demographics for all outcomes and the composite cognitive measure for test scores and eighth-grade MCAS scores for cognitive measures is shown in (c), and the graph in (d) shows variance when controlling for student demographics and fourth-grade MCAS scores across all measures but excluding students from exam schools.

with additional controls for either eighth-grade MCAS scores (in the analyses of cognitive measures) or cognitive performance measured in eighth grade (in the analyses of eighth-grade MCAS scores). Specifically, the same pattern was observed when we controlled for three additional sets of factors. First, we controlled for eighth-grade MCAS performance in assessing how much variation the school a student attended explained in cognitive measures, and we controlled for cognitive performance (composite cognitive measure) in assessing how much variation schools explain in achievement (math and ELA MCAS; Fig. 2b). Next, we removed the controls for fourth-grade MCAS performance in the original analysis and controlled for eighth-grade MCAS performance in assessing how much variation schools explain in cognitive measures, and we controlled for cognitive performance (composite cognitive measure) in assessing how much variation schools explain in achievement (math and ELA; Fig. 2c). Finally, we excluded exam schools, which selectively admit students on the basis of test scores (Fig. 2d). Even when controlling for cognitive skill and achievement in various ways, we found that schools consistently accounted for a large amount of variation in achievement-test scores but minimal variation in cognitive measures.

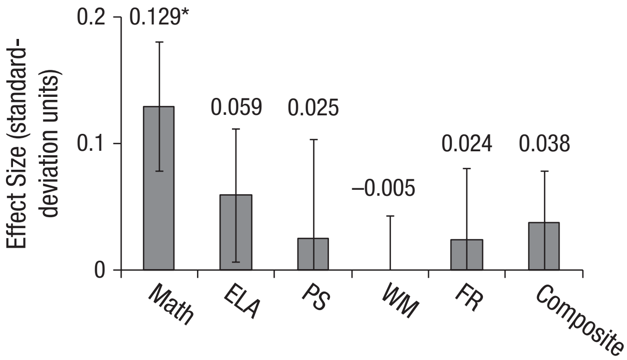

Fig. 3. Estimated impact of 1 year's attendance at an oversubscribed charter school as a function of Massachusetts Comprehensive Assessment System (MCAS) scores on tests of math and English language ability (ELA) as well as cognitive measures of processing speed (PS), working memory (WM), fluid reasoning (FR), and a composite cognitive measure. Quasiexperimental estimates (based on random offer of admission) depict the effect of each additional year of charter attendance on MCAS scores and cognitive skills. Error bars represent ±1 standard error of the estimated effect. The asterisk represents a significant effect ($p < .05$).

Impact of charter-school attendance on MCAS scores and cognitive measures

In a second, quasiexperimental analysis, we directly examined the relationship between charter-school attendance on both MCAS scores and cognitive measures by asking whether five oversubscribed charter schools that improved MCAS scores also improved cognitive skills. Following a study of oversubscribed charter schools (Abdulkadiroglu et al., 2011), we used the random offer of enrollment to these schools to estimate the effect of charter attendance on MCAS scores and cognitive skills. Outcomes were compared between eighth graders who applied and randomly won ($n = 143$) or lost ($n = 57$) the lottery for admission to these charter schools, with adjustments made for the fact that not all lottery winners entered and remained enrolled in a charter school. Following previous work (Abdulkadiroglu et al., 2011), we fit the following model:

$$Y_{is} = \alpha A_{i,t-4} + \beta \text{Years}_{is} + \lambda X_i + \sum_j \delta_j d_{ij} + \epsilon_{is}$$

The outcome of interest (Y_{is}) represents a given test score or measure of cognitive skill for student i in school s. We included as controls lagged fourth-grade scores in math and ELA ($A_{i,t\text{–}4}$) and a vector of student demographic characteristics (X_i) consisting of variables for gender, race, age, free- and reduced-priced-lunch status, limited English proficiency, and special-education status. The set of indicator variables d_{ij} controlled for lottery "risk sets," or the unique combination of lotteries to which each student applied, indexed by j. Parameter β represents the quantity of interest, the effect of attending a year at one of the five oversubscribed charter schools.

To arrive at a causal estimate of β, we isolated exogenous variation in Years_i, our measure of the number of years a student attended a charter school. We did this by employing the random (within-lottery "risk sets") offer of enrollment as an instrument for charter attendance with the following first-stage model:

$$\text{Years}_{is} = \gamma_1 \text{Offer}_i + \theta A_{i,t-4} + \tau X_i + \sum_j \rho_j d_{ij} + \xi_{is}$$

The indicator variable for whether a student was randomly offered enrollment to any of the five charter schools, Offer_i, provides a valid instrument for Years_{is}. We also included the full set of covariates from the second-stage model above. See the Supplemental Material for additional information about this and other data analyses.

Each additional year of charter attendance was estimated to increase eighth-grade math scores by 0.129 standard deviations ($p = .018$), with no significant effects for ELA scores. Despite the increase in MCAS math scores, we observed virtually no effect of oversubscribed charter-school attendance on cognitive skills, considered individually or as a composite (Fig. 3).[1]

Discussion

This study is the first to relate scores on statewide standardized achievement tests to measures of cognitive skills in a large and representative sample of students in a city that includes traditional district, exam, and charter public schools. We found substantial positive correlations between cognitive skills and achievement-test scores, especially in math. These correlations are consistent with prior studies relating working memory to academic performance (grades) in United Kingdom schools (Alloway & Alloway, 2010; Alloway & Passolunghi, 2011; Gathercole et al., 2004; St Clair-Thompson & Gathercole, 2006). We also extend prior research by documenting a relationship between cognitive skills and the growth of achievement-test scores from fourth to eighth grade.

However, two convergent findings suggested that the school a student attended in the district we studied played little role in the growth of cognitive skills. First, which school students attended explained substantial variance in students' achievement scores but not in measures of their cognitive skills. Second, the sample included winners and losers of lotteries for oversubscribed charter schools. In Massachusetts, students who won admission to and attended urban charter schools through these lotteries achieved substantial test-score gains above those students that lost the lotteries (Abdulkadiroglu et al., 2011). We replicated that finding for math (but not ELA) scores (school impacts are frequently larger on math scores than on ELA scores). Attending a charter school as a result of winning a seat through an admission lottery, however, did not significantly affect students' cognitive skills. These findings suggest that school practices that influence standardized achievement tests have limited effects on the development of cognitive skills associated with processing speed, working memory, or fluid reasoning.

The present study has multiple caveats. First, our sample was limited to 1,367 students in 32 schools of the 3,151 students in 49 schools from one district who took the MCAS in both fourth and eighth grade. One source of potential bias was parental consent for student participation, a bias that may favor students from more supportive households. The sample of students from traditional district schools scored higher on the statewide tests than did the overall population in these schools, which suggests that the sample from these schools was biased toward higher-achieving students. Second, although analysis of the effects of attending a charter school has the rare benefit of being able to exploit the random offer of enrollment to make quasiexperimental comparisons, there were especially few lottery losers in this sample.

Although the lottery-based admission of students to oversubscribed charter schools creates a natural experiment among lottery applicants, the present study is neither an evaluation of charter schools in general, nor a direct comparison of charter, traditional, and exam schools. Gains in student achievement varied across all three school types, with some traditional schools having higher average gains than some charter schools (Fig. S4 in the Supplemental Material).

The finding that variation in schooling influences crystallized but not fluid intelligence is consistent with a population study of over 100,000 males in Sweden (Carlsson, Dahl, & Rooth, 2012). Crystallized and fluid intelligence are typically correlated, as were the MCAS and cognitive-skills measures in the present study, and it appears that effective schools, including the oversubscribed charter schools and some of the traditional district schools in the present study, may be decoupling these two kinds of intelligence.

These findings raise the question of what kinds of abilities are indexed by high-stakes statewide standardized tests that are widely used as a measure of educational effectiveness. Several lines of evidence indicate that students' scores on standardized achievement tests predict important long-term educational and socioeconomic outcomes. Student achievement scores in math and reading at age 7 years are associated positively with adult socioeconomic status (SES) and educational attainment at age 42 even after controlling for SES at birth and for intelligence measures (Ritchie & Bates, 2013). Further, charter high schools that produce large gains on standardized tests also improve student performance on Advanced Placement tests and SATs (especially in math, as in the present study; Angrist et al., 2013). Finally, gains in standardized test scores due to classroom quality (i.e., class size and teacher effectiveness) in primary school are also associated with positive SES outcomes in adulthood (Chetty et al., 2011). It is unknown, however, how a selective enhancement of crystallized intelligence, without the enhancement of typically correlated fluid intelligence, translates into long-term benefits for students and whether additional enhancement of fluid intelligence would further bolster long-term educational and SES outcomes.

Although school-level educational practices that enhance standardized test scores may not increase broader, fluid cognitive abilities, there is evidence that targeted interventions—both in and out of school— may increase cognitive ability. Preschoolers enrolled in a year-long executive function training curriculum improved performance on untrained executive function tests (Diamond, Barnett, Thomas, & Munro, 2007). Children receiving an intervention emphasizing the development of cognitive and conceptual skills (among other interventions, "the Abecedarian Project") from birth to either 5 or 8 years of age, performed better on both standardized intelligence (IQ) and academic tests (Campbell, Ramey, Pungello, Sparling, & Miller-Johnson, 2002). Teaching inductive reasoning to third- and fourth-grade students improved performance on untrained reasoning tests and a fluid-reasoning measure (Raven's Progressive Matrices) if the intervention lasted for 2 years (de Koning, Hamers, Sijtsma, & Vermeer, 2002). Seventh graders in Venezuela showed gains on multiple standardized tests following an intensive year of cognitive training, although the benefits were not apparent on tests characterized as reflecting fluid, content-independent cognitive skills (Herrnstein, Nickerson, & de Sánchez, 1986). Eight-week training in after-school programs focused on either reasoning or speed training selectively enhanced performance in 7- to 9-year-olds (Mackey, Hill, Stone, & Bunge, 2011).

In addition to the above in-school studies, interventions performed outside of school have also shown that working memory or attention-training exercises conducted over the course of several weeks can improve cognitive skills beyond those that are trained directly (Bergman Nutley et al., 2011; Klingberg, 2010; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005) and improve performance on tests of math and literacy (Maridaki-Kassotaki, 2002; Rajah, Sundaram, & Anandkumar, 2011; Witt, 2011). Although a broader understanding of which aspects of cognitive skill are malleable and which interventions are effective and why is still emerging, the above studies indicate that targeted interventions may boost cognitive skills in students.

In sum, the present study provides further evidence that schools influence standardized test scores that reflect crystallized knowledge. The growth of math and language skills that schools can support may be especially important for students growing up in disadvantaged environments that typically offer fewer opportunities for academic enrichment outside of school. The same schools, however, had no apparent influence on cognitive skills reflecting fluid intelligence. Given the evidence that cognitive skills were associated with not only standardized test scores but also with the growth of those scores from fourth to eighth grade, students may further benefit from school practices that enhance cognitive skills. The development of curriculum that fosters the growth of cognitive skills may further nurture the academic and long-term success of students.

Author Contributions

A. S. Finn, J. D. E. Gabrieli, C. F. O. Gabrieli, and M. A. Sheridan designed the study. M. A. Kraft, M. R. West, and A. S. Finn analyzed the data. A. S. Finn, J. A. Leonard, C. E. Bish, and R. E. Martin collected and organized the data. A. S. Finn, M. A. Kraft, M. R. West, and J. D. E. Gabrieli wrote the manuscript.

Acknowledgments

We thank J. Salvatore, B. Khalil Peabody, and A. Mackey for assistance in this research.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Funding

This research was funded by the Bill & Melinda Gates Foundation (to J. D. E. Gabrieli and C. F. O. Gabrieli) and the National Institute of Health (National Research Service Award to A. S. Finn).

Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Note

1. Sample sizes for these analyses vary because of missing data on cognitive measures—n = 200 (MCAS math, MCAS ELA, and processing speed), n = 188 (working memory), n = 185 (fluid reasoning), n = 176 (composite).

References

Abdulkadiroglu, A., Angrist, J. D., Dynarski, S. M., Kane, T. J., & Pathak, P. A. (2011). Accountability and flexibility in public schools: Evidence from Boston's charters and pilots. *The Quarterly Journal of Economics*, *126*, 699–748.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*, 20–29.

Alloway, T. P., & Passolunghi, M. C. (2011). The relationship between working memory, IQ, and mathematical skills in children. *Learning and Individual Differences*, *21*, 133–137.

Angrist, J. D., Cohodes, S. R., Dynarski, S. M., Pathak, P. A., & Walters, C. D. (2013). *Charter schools and the road to college readiness: The effects on college preparation, attendance and choice*. Retrieved from http://www.tbf.org/~/media/TBFOrg/Files/Reports/Charters%20and%20College%20Readiness%202013.pdf

Bergman Nutley, S., Soderqvist, S., Bryde, S., Thorell, L. B., Humphreys, K., & Klingberg, T. (2011). Gains in fluid intelligence after training non-verbal reasoning in 4-year-old children: A controlled, randomized study. *Developmental Science*, *14*, 591–601.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647–663.

Borman, G. D., Hewes, G. M., Overman, L. T., & Brown, S. (2003). Comprehensive school reform and achievement: A meta-analysis. *Review of Educational Research*, *73*, 125–230.

Brown, L., Sherbenou, R. J., & Johnsen, S. K. (2010). *Test of Nonverbal Intelligence—Fourth edition (Version A)*. San Antonio, TX: The Psychological Corp.

Burrage, M. S., Ponitz, C. C., McCready, E. A., Shah, P., Sims, B. C., Jewkes, A. M., & Morrison, F. J. (2008). Age- and schooling-related effects on executive functions in young children: A natural experiment. *Child Neuropsychology*, *14*, 510–524.

Campbell, F. A., Ramey, C. T., Pungello, E., Sparling, J., & Miller-Johnson, S. (2002). Early childhood education: Young adult outcomes from the Abecedarian Project. *Applied Developmental Science*, *6*, 42–57.

Carlsson, M., Dahl, G. B., & Rooth, D.-O. (2012, October). *The effect of schooling on cognitive skills* (Working Paper No. 18484). Retrieved from http://www.nber.org/papers/w18484

Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, *33*, 386–404.

Cattell, R. B. (1967). The theory of fluid intelligence and crystalized intelligence in relation to "culture fair" tests and its verification in children 9–12 years old. *Revue de Psychologie Appliquée*, *17*, 135–154.

Ceci, S. J. (1991). How much does schooling influence general intelligence and its cognitive components? A reassessment of the evidence. *Developmental Psychology*, *27*, 703–722.

Ceci, S. J., & Williams, W. M. (1997). Schooling, intelligence, and income. *American Psychologist*, *52*, 1051–1058.

Chetty, R., Friedman, J. N., Hilger, N., Saez, E., Schanzenbach, D. W., & Yagan, D. (2011). How does your kindergarten classroom affect your earnings? Evidence from Project Star. *The Quarterly Journal of Economics*, *126*, 1593–1660.

Cowan, N. (2005). *Working memory capacity: Essays in cognitive psychology*. New York, NY: Psychology Press.

Cowan, N., Elliott, E. M., Saults, S. J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology*, *51*, 42–100.

Coyle, T. R., Pillow, D. R., Snyder, A. C., & Kochunov, P. (2011). Processing speed mediates the development of general intelligence (*g*) in adolescence. *Psychological Science*, *22*, 1265–1269.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*, 450–466.

de Koning, E., Hamers, J. H. M., Sijtsma, K., & Vermeer, A. (2002). Teaching inductive reasoning in primary education. *Developmental Review*, *22*, 211–241.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*, 1387–1388.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102–134). New York, NY: Cambridge University Press.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*, 309–331.

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence. *Psychological Science*, *7*, 237–241.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from National Curriculum Assessments at 7 and 14 years of age. *Applied Cognitive Psychology*, *18*, 1–16.

Hanushek, E. A., & Rivkin, S. G. (2010). Generalizations about using value-added measures of teacher quality. *American Economic Review*, *100*, 267–271.

Herrnstein, R. J., Nickerson, R. S., & de Sánchez, M. (1986). Teaching thinking skills. *American Psychologist*, *41*, 1279–1289.

Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica*, *86*, 199–225.

Kail, R. V. (2007). Longitudinal evidence that increases in processing speed and working memory enhance children's reasoning. *Psychological Science*, *18*, 312–313.

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, *14*, 317–324.

Mackey, A. P., Hill, S. S., Stone, S. I., & Bunge, S. A. (2011). Differential effects of reasoning and speed training in children. *Developmental Science*, *14*, 582–590.

Maridaki-Kassotaki, K. (2002). The relation between phonological memory skills and reading ability in Greek-speaking children: Can training of phonological memory contribute to reading development? *European Journal of Psychology of Education*, *17*, 63–75.

Massachusetts Department of Elementary & Secondary Education. (2011). *Massachusetts Comprehensive Assessment System*. Boston, MA: Author.

McClelland, M. M., Acock, A. C., Piccinin, A., Rhea, S. A., & Stallings, M. C. (2013). Relations between preschool attention span-persistence and age 25 educational outcomes. *Early Childhood Research Quarterly*, *28*, 314–324.

McCrea, S. M., Mueller, J. H., & Parrila, R. K. (1999). Quantitative analyses of schooling effects on executive function in young children. *Child Neuropsychology*, *5*, 242–250.

Rajah, A., Sundaram, K. R., & Anandkumar, A. (2011). Changes in intellectual and academic performance of children following computer-based training: Preliminary results. *Indian Journal of Psychiatry*, *53*, 249–252.

Ritchie, S. J., & Bates, T. C. (2013). Enduring links from childhood mathematics and reading achievement to adult socioeconomic status. *Psychological Science*, *24*, 1301–1308.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences, USA*, *102*, 14931–14936.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology*, *59*, 745–759.

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children—Fourth edition*. San Antonio, TX: The Psychological Corp.

Witt, M. (2011). School based working memory training: Preliminary finding of improvement in children's mathematical performance. *Advances in Cognitive Psychology*, *7*, 7–15.