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The Virginia Department of Education's Virtual Virginia (VVA) program delivers more than 90 supplemental online courses to more than 10,000 middle and high school students each year. The department partnered with Regional Educational Laboratory (REL) Appalachia to examine the relationship between students' participation in a subset of 31 VVA online courses and their performance on end-of-course Virginia Standards of Learning (SOL) and Advanced Placement (AP) exams during the 2015/16 and 2016/17 school years. Relying on administrative records available through the Virginia Longitudinal Data System, REL Appalachia researchers conducted descriptive analyses and regression analyses with statistical controls. After controlling for demographic and prior achievement differences, students in face-to-face courses were more likely to score higher and demonstrate proficiency on SOL and AP exams than students taking the same courses through VVA across most subject areas. Because the study design was correlational, additional research is needed to determine whether the difference in performance is due to the characteristics of the students in online courses, aspects of the VVA program itself, or some other factor such as students' reasons for enrolling in the course or the supports available in their local schools.

Why this study?

Online learning has been a growing trend in K–12 education since the 1990s. During the 2014/15 school year, approximately 2.7 million students were enrolled in K–12 online learning programs in the United States as a supplement to their regular instruction (Gemin, Pape, Vashaw, & Watson, 2015). Five states—including Virginia—now require students to complete at least one online course before high school graduation (Herold, 2017). This growth is driven by diverse interests, including expanding the range of courses available to students, offering increased flexibility for students with scheduling conflicts or who are otherwise unable to attend regular school, providing credit recovery options for students who have failed courses, and reducing per-pupil costs (U.S. Department of Education, Office of Educational Technology, 2012; Wicks, 2010).

State-operated programs are a key supplier of online courses to schools and districts (Gemin & Pape, 2016), operating in 23 states and serving about 420,000 students with almost a million course enrollments in the 2017/18 fiscal year (Digital Learning Collaborative, 2019). Virtual Virginia (VVA), a program of the Virginia Department of Education (VDOE), serves more than 10,000 middle and high school students per year. VVA offers access to more than 90 supplemental online courses for Virginia students who otherwise may not be able to take Advanced Placement (AP), languages, core academic, and elective courses because of a lack of highly qualified instructors, insufficient student enrollment for a local course, or scheduling conflicts in a school. Eligible students enroll in VVA courses through their local schools (box 1). Starting in the 2014/15 school year, VVA expanded to support a

full-time enrollment model that offers all the core academic courses and electives required to earn a high school diploma.[1] The full-time program serves approximately 200 students.

Even as more students take online courses, evidence on the effectiveness of online learning programs is still sparse, with few rigorous published studies of the effectiveness of online learning for K–12 students (U.S. Department of Education, Office of Planning, Evaluation, and Policy Development, 2010; Brodersen & Melluzzo, 2017). Findings from two of the most methodologically rigorous experimental studies are mixed, suggesting that at least some students may be able to benefit from online courses under some circumstances. For example, one study looking at the effectiveness of online courses for credit recovery found that students in online credit recovery courses were less likely to recover credit and scored lower on an algebra posttest than students in face-to-face credit recovery courses (Heppen et al., 2016a). Another study focused on the effectiveness of online courses to expand course access found that offering online algebra I in grade 8 to algebra-ready students in schools that do not typically offer the course positively impacted students' algebra achievement and subsequent course taking (Heppen et al., 2011). This indicates a potential benefit to offering virtual learning opportunities to increase course availability when the course is not available face-to-face, one of the stated goals of VDOE's VVA program.

With limited and inconclusive evidence on online learning in Virginia and nationwide, Virginia's 2014 Appropriation Act (Virginia General Assembly, 2014) directed VDOE to analyze and report student effectiveness data for online programs. In response, the Virginia Joint Legislative Audit and Review Commission (2015) recommended that VDOE conduct ongoing analyses comparing student outcomes in VVA and face-to-face courses to explore the quality of online programs and support fiscally responsible use of state resources.

As virtual learning in Virginia expands, the Virginia Board of Education, state legislators, and members of VDOE's Virtual Learning Advisory Committee seek evidence to inform policy, program, and funding decisions. VDOE partnered with Regional Educational Laboratory (REL) Appalachia to begin examining how student achievement in VVA courses compared to student achievement in face-to-face courses.[2]

This study provides descriptive information regarding participation in VVA courses and examines associations between participation in VVA courses and student academic performance. The study design is correlational, which does not allow for definitive conclusions about the impact of VVA on student achievement. Additionally, the researchers had access to virtual and face-to-face course *enrollments*, but not course *offerings* and so were unable to examine the benefit of increasing course availability through virtual means. However, the results can be used in discussions of virtual learning at the state and local levels, and they lay the groundwork for additional study.

Box 1. The Virtual Virginia program

The following description of the Virtual Virginia model was adapted by the authors from the program website.[3]

Curriculum. Teams of content area experts, online learning experts, and instructional designers build the web-based courses for Virtual Virginia (VVA). Course materials include readings, simulations, interactive practice, video files, and audio files. VVA's courses are aligned with the Virginia Standards of Learning (SOLs), and VVA's Advanced Placement (AP) courses have been approved by the College Board.

[1] Full-time enrollment is defined as simultaneous enrollment in five or more VVA courses. Students move in and out of the full-time enrollment program based on the number of courses they take at one time. Supplemental enrollment is defined as simultaneous enrollment in four or fewer VVA courses.

[2] Before partnering with REL Appalachia, VDOE researchers examined the pass rates and end-of-course exam scores for students in VVA courses. Although not the focus of this study, students' unadjusted performance in VVA courses is presented in the technical appendix (exhibit A19).

[3] Source: https://www.virtualvirginia.org/

Instructors. VVA has both full-time and adjunct instructors who are Virginia-licensed, highly qualified, have experience in distance learning, and reside in Virginia. VVA provides instructors with professional development training in specific content areas and best practices of online instruction. VVA instructors manage the online course (set the pace, score student work) and work with students individually and in small groups online and by telephone to facilitate discussions, answer questions, and provide customized instruction.

Enrollment. Students in Virginia middle and high schools who meet the course prerequisites and have approval from the local school counselor may enroll in VVA courses through their schools. Recommendations concerning instructional placement of the student are the responsibility of the local school counselor. Across schools, counselors have varied discretion in determining which students are eligible for and could succeed in online courses.

Access and pacing. Students move through VVA course material at the pace of their cohort/start date. Instructors establish benchmark due dates to ensure that students stay on pace to complete the course by the end of the term/school year, but students have flexibility between those due dates. Students do not have to take VVA courses in 'real' time and can access courses 24/7 from any Internet-accessible location.

Local implementation conditions and supports. VDOE and VVA do not prescribe or require a specific program model. There is a great deal of variation in the reasons for, and ways in which, students, schools, and school divisions use VVA. For example, some students take VVA courses during the school day in a computer lab monitored by a facilitator, while others take VVA courses at home using a personal device.

Exams and grading. VVA awards students a numerical average for each course they complete. The local school then assigns credit and the appropriate letter grade for this average based on the school's grading scale. Students enrolled in VVA courses that include an SOL exam must take the test through their local school. VVA encourages but does not require students in VVA AP courses to take the corresponding AP exam.

Costs. During the academic year, each Virginia public school may enroll up to 15 students per course with no enrollment fees. Local schools are responsible for ensuring that students in the program have access to student services, technology, textbooks, and other necessary materials at no cost. VVA summer session courses cost $375 per course.

Research questions

This study addressed two primary research questions to explore the relationship between students' participation in VVA courses and their short-term academic success as measured by standardized test score outcomes:

1. *How do the demographic characteristics compare between students who enrolled in and completed Virtual Virginia courses and the standardized end-of-course exams and students who took the same courses and exams face to face?*
2. *How do students who enrolled in and completed Virtual Virginia courses and the standardized end-of-course exam perform, compared to similar students who took the same courses and exams face to face?*

Answering these questions provides information on the extent to which student achievement is comparable for the two available instructional modes. Controlling for differences in demographics and prior achievement enables a comparison between similar students in each group. Key terms used in this report are defined below (box 2).

Box 2. Key Terms

Advanced Placement (AP) course. College-level courses developed by the College Board's AP Program that high schools can choose to offer along with corresponding exams that are administered once a year. AP exams are scored on a scale of 1 to 5.

Many U.S. colleges and universities grant students course credit, advanced course placement, or both for AP exam scores of 3 or higher.[4]

Core academic course. A course required to earn a high school diploma.

Division. Local education agencies in Virginia, which are similar to school districts in some other states.

Economically disadvantaged. A VDOE designation that identifies a student who meets any one or more of the following: is eligible for free or reduced-price meals, receives assistance from the Temporary Assistance for Needy Families program, is eligible for Medicaid, or is identified as either a migrant or experiencing homelessness.

End-of-course exam. Term used throughout this report to refer to Advanced Placement (AP) exams and Virginia Standards of Learning (SOL) exams.

Face-to-face course. Course taken in person in a traditional classroom setting.

Full-time course enrollment model. Defined by VDOE as concurrent enrollment in five or more VVA courses.

Gifted. A VDOE designation identifying a student who demonstrates high levels of accomplishment or who shows the potential for higher levels of accomplishment when compared with others of the same age, experience, or environment. The aptitudes and potential of gifted students for accomplishment are so outstanding that they require special programs to meet their education need. Each school division in Virginia establishes procedures for the identification of gifted students and for the delivery of services to those students, consistent with the *Regulations Governing Educational Services for Gifted Students*. Eligibility decisions must be based on multiple criteria which may include test scores.

Locale classification. A general geographic indicator developed by the National Center for Education Statistics Education Demographic and Geographic Estimates program that categorizes U.S. territory into four types of areas: city, suburban, town, and rural.

Online course. Any course offered in which instruction and content are delivered primarily over the Internet; synonymous with e-course, virtual course, and cyber course.

Standards of Learning (SOLs). The minimum expectations for what Virginia public school students should know and be able to do at the end of each grade or course in English, mathematics, science, history/social science, and other subjects. SOL exams measure students' success in meeting the Board of Education's expectations for learning and achievement. Student performance is graded on a scale of 0–600, with 400 representing the minimum level of acceptable proficiency.

Subject area. Synonymous with content area or domain. Examples include English language arts, mathematics, and science.

Substantive importance. An effect size—a standardized measure of the magnitude of the difference in outcomes or characteristics between groups—equal to or greater than 0.25.

Supplemental course enrollment model. Defined by the Virginia Department of Education as concurrent enrollment in four or fewer Virtual Virginia (VVA) courses.

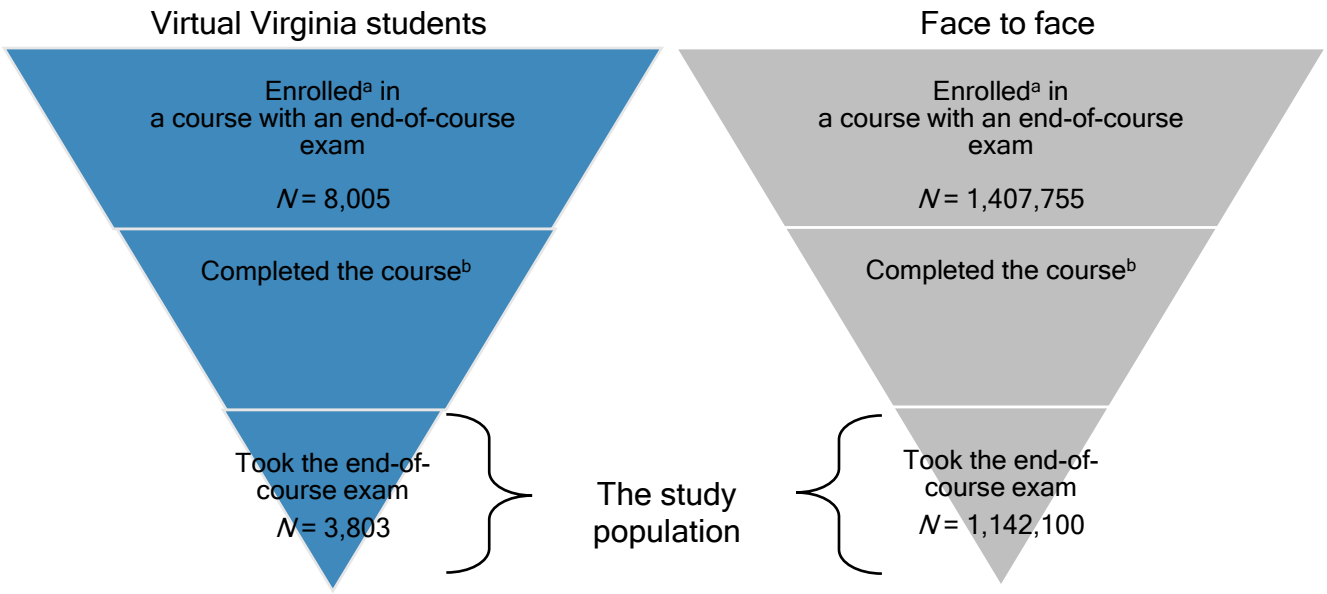
Study population

To compare course-related test scores of students taking the same course through face-to-face instruction and VVA, researchers constrained the study population to those courses that had an end-of-course standardized test and to those students who enrolled in and completed the course and who also took the end-of-course exam. In 2015/16 and 2016/17, about 8,000 students enrolled in a VVA course that had an associated end-of-course exam (exhibit 1). About 3,800 (48 percent) of those students completed the course and took the end-of-course test. In contrast, about 1.41 million students enrolled in the same courses face to face, and about 1.14 million (81 percent)

[4] Source: https://apstudents.collegeboard.org/about-ap-scores

of those students competed the course and took the end-of-course exam. Although students' reasons for not completing the course or the end-of-course exam in either instructional mode are unknown, these patterns are consistent with prior research findings that online courses often have a higher noncompletion rate than face-to-face courses (Bawa, 2016; Freidhoff, 2016).[5]

Exhibit 1. The population for the study comprised Virginia students who enrolled in and completed the course, and took the associated end-of-course exam during the 2015/16 and 2016/17 school years



[a] Enrollment in a Virtual Virginia course reflects a record of a course account created for the student. In some cases, schools upload entire rosters of students, often not knowing which students plan to enroll and which students do not. It is not possible to determine from the available administrative data whether individual students who have a course account were enrolled or part of a larger roster of students who may or may not enroll in the course. As such, these counts may over-estimate the number of students enrolled in VVA courses.
[b] The Virginia Longitudinal Data System does not include an indicator for course completion. The visualization depicts a decrease in the number of students (N) between course completion and exam completion, although the exact change in numbers, if any, cannot be determined from the available data. It is possible that the number of students who completed the course is equal to the number who took the end-of-course exam.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Study design

REL Appalachia researchers reviewed available administrative data sources (box 3) to determine the most rigorous study design possible using existing data. In consultation with VDOE and the Institute for Education Sciences, researchers selected a correlational design using regression analyses. Those analyses sought to take into account factors related to students and schools that might influence differences in exam scores between VVA and face-to-face courses. However, regression could only account for factors for which data were available in the Virginia Longitudinal Data System (VLDS), which included prior test scores, student demographics, and school characteristics. Even after accounting for these factors, there are likely other important differences between students in the VVA and face-to-face conditions that this study did not address. For example, the current study did not include data on the following:

[5] The reasons for course "withdrawals" prior to test completion are very limited in the data that VDOE collects, and the information that is recorded is too unreliable to report. For this reason, we do not provide any additional information on the group of students who enrolled in a VVA course but did not complete the associated end-of-course SOL or AP exam.

- Students' reasons for enrolling in a VVA course, such as to take a course not offered at their local school, to recover credit for a course they previously failed in a face-to-face setting,[6] or because they were homebound.[7]
- Student characteristics such as self-motivation, self-discipline, and time management skills.
- Differences in school-level implementations of VVA, including the kinds of students whom school counselors identify to take online courses and the supports available to students.
- Students' reasons for taking or not taking end-of-course exams, nor the reason fewer of the VVA students completed end-of-course exams than their face-to-face course peers.

Research has shown these factors may also be related to student persistence and performance in online courses (Bawa, 2016; Hung, Hsu, & Rice, 2012; Kim, Park, & Cozart, 2014; Liu & Cavanaugh, 2011; Rice, 2006; Roblyer, Davis, Mills, Marshall, & Pape, 2008). Therefore, the correlations reported in this study may be attributable, in part, to these unmeasured factors.

Box 3. Data sources, population, and methods

For details on the data sources, population, methodology, and results, see *Comparing the Achievement of Students in Virtual Virginia and Face-to-Face Courses: Report Technical Appendices* (Mislevy, Schmidt, Puma, Ezekoye, & Saucedo 2020).

Data sources. The Virginia Department of Education (VDOE) provided the data for these analyses through the Virginia Longitudinal Data System. The de-identified administrative records were at the student level and included student demographic variables, online and face-to-face course records, and achievement test scores. The dataset also included information on the student's school of record, which researchers used to link in the locale classification from the National Center for Education Statistics' Common Core of Data and the percentage of the region in which the school was located that was rural from the United States Census.

Population. The study population consisted of all Virginia public school students in grades 8–12 who enrolled in courses with either SOL or AP exams during the 2015/16 and 2016/17 school years.[8] This comprised a total of 24 AP courses and seven core academic courses with SOL exams.[9] To be included in the study population, students needed to complete the end-of-course exam.

Because no significant changes were made to the SOL or AP exams or to the online courses between 2015/16 and 2016/17, researchers aggregated data across the two school years to increase the available number of online students. Researchers also combined exam scores across courses in the same subject area. For example, algebra I, geometry, and algebra II SOL exam scores contributed to the "mathematics SOL" outcome.

[6] The VLDS does not include an indicator for credit recovery courses, and observance of a student taking a course more than once does not systematically and reliably identify prior course failure. It is possible for a student to pass an end-of-course assessment and fail the course, and it is also possible for a student to fail an end-of-course assessment and pass the course (VDOE, 2009).

[7] The VLDS does not include an indicator for homebound students.

[8] 2015/16 was the first year VVA began tracking students' unique state testing identifiers in its student information system, the linking variable needed to link VVA records to VDOE administrative records.

[9] Although students in Virginia are also required to pass an SOL exam in history or social science, this study focuses on math, science, and English language arts core academic courses because they were the focus of VDOE's prior analysis of unadjusted outcomes (analyses that did not include statistical controls for student demographic characteristics, prior achievement, or other factors). VDOE researchers excluded history/social science courses for several reasons. History is no longer a consideration for state accreditation and has a diminished presence in federal accountability. Additionally, VDOE recently reduced the number of verified credits required in history to 1, which has in turn reduced testing in history. Instead, history has been an important piece of VDOE's focus on developing and implementing performance-based assessments in lieu of standardized testing. Lastly, unlike the other subject areas, testing in history is not always sequential and ordered.

Methodology. Two methodological approaches were used to address the research question. First, descriptive statistics were used to examine the characteristics of students who enrolled in and completed the end-of-course exam through VVA or in comparable face-to-face courses.

Second, regression analysis was used to examine the relationship between VVA and SOL and AP exam scores while adjusting for the influence of other available student characteristics. Researchers included statistical controls for students' grade level, race, gender, rurality, and economic status, as well as their prior test scores.

The regressions pooled exam scores across courses within each subject area. Because these exams were not scored on the same scale,[10] researchers used an accepted transformation to create a common outcome metric known as *z*-scores.[11]

Researchers also used regression with statistical controls to examine the relationship between taking the course through VVA and demonstrating proficiency on SOL and AP exams. For these analyses, proficiency was defined as achieving a score of 400 or above on an SOL exam or 3 or above on an AP exam.

REL Appalachia researchers used the criterion set by the What Works Clearinghouse (WWC, 2017) to determine the substantive importance of the differences in outcomes or characteristics between the students in VVA and face-to-face courses: an effect size—a standardized measure of the magnitude of the difference—of 0.25 or greater.[12] [13]

Findings

Students who enrolled in Virtual Virginia online courses represented a small fraction of all students who completed the associated end-of-course exams virtually or face-to-face.

Face-to-face instruction was by far the more common mode of instruction for the courses and students in the study. In the population, 426 students were enrolled in VVA core academic courses and completed SOL exams, and 3,377 students were enrolled in VVA AP courses and completed AP exams during the 2015/16 and 2016/17 school years (exhibit 2). VVA comprised just 0.05 percent of the total population in core academic courses, and 2 percent of the total population in AP courses.

[10] Unlike the grade 3–8 SOL exams, which are vertically equated—that is, scored on the same scale across grades to allow for the direct comparison of performance across grade levels—the end-of-course SOLs that are the focus of this study are not equated to provide comparable scores across courses (VDOE, 2019). For all SOL exams, a score of 400 represents the minimum level of acceptable proficiency. However, outside this cut point, a score of 430 on the end-of-course exam for one course (for example, algebra I) may not be comparable to a score of 430 on the end-of-course exam for another course (for example, geometry).

[11] For each end-of-course test, REL Appalachia researchers created z-scores by subtracting the mean score for that test from each student's test score and dividing it by the standard deviation. Researchers commonly use this approach to put different tests on a comparable metric or scale. See, for example, May, Perez-Johnson, Haimson, Sattar, and Gleason (2009) and Clark, Isenberg, Liu, Makowsky, and Zukiewicz (2017).

[12] In accordance with IES guidance, REL Appalachia researchers did not conduct statistical significance testing because the study data cover the entire population of interest. Statistical tests are typically meant to make inferences about a population when the data cover only a sample from that population. When data come from a census, there is no statistical uncertainty in descriptive findings (with some exceptions, such as when data are missing). Differences between groups in the data are, in fact, the true differences in the population.

[13] For continuous outcomes such as test scores, the WWC has adopted the most commonly used effect size index, the standardized mean difference known as Hedges' g. The WWC's effect size measure of choice for dichotomous outcomes is the Cox index, which yields effect size values similar to the values of Hedges' g. Both effect size indices increase magnitude as the difference between the groups on the outcome measure get larger; however, Cox's index also increases as proportions approach 0 or 1.

Exhibit 2. Students who enrolled in Virtual Virginia online courses represented a small fraction of students who completed the associated end-of-course exams virtually or face-to-face, 2015/16–2016/17

Outcome and subject area	Face-to-face population	Virtual Virginia population
Core academic courses	**927,811**	**426**
Mathematics SOL	417,792	201
English language arts SOL	381,970	154
Science SOL	128,049	71
AP courses	**214,289**	**3,377**
AP languages	3,417	136
AP history/social science	106,974	2,143
AP science	27,859	437
AP English language arts	41,835	291
AP mathematics	34,204	370

Note: AP is Advanced Placement. SOL is Standards of Learning.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Students who took Virtual Virginia online courses and completed associated end-of-course exams were demographically different from their face-to-face course peers.

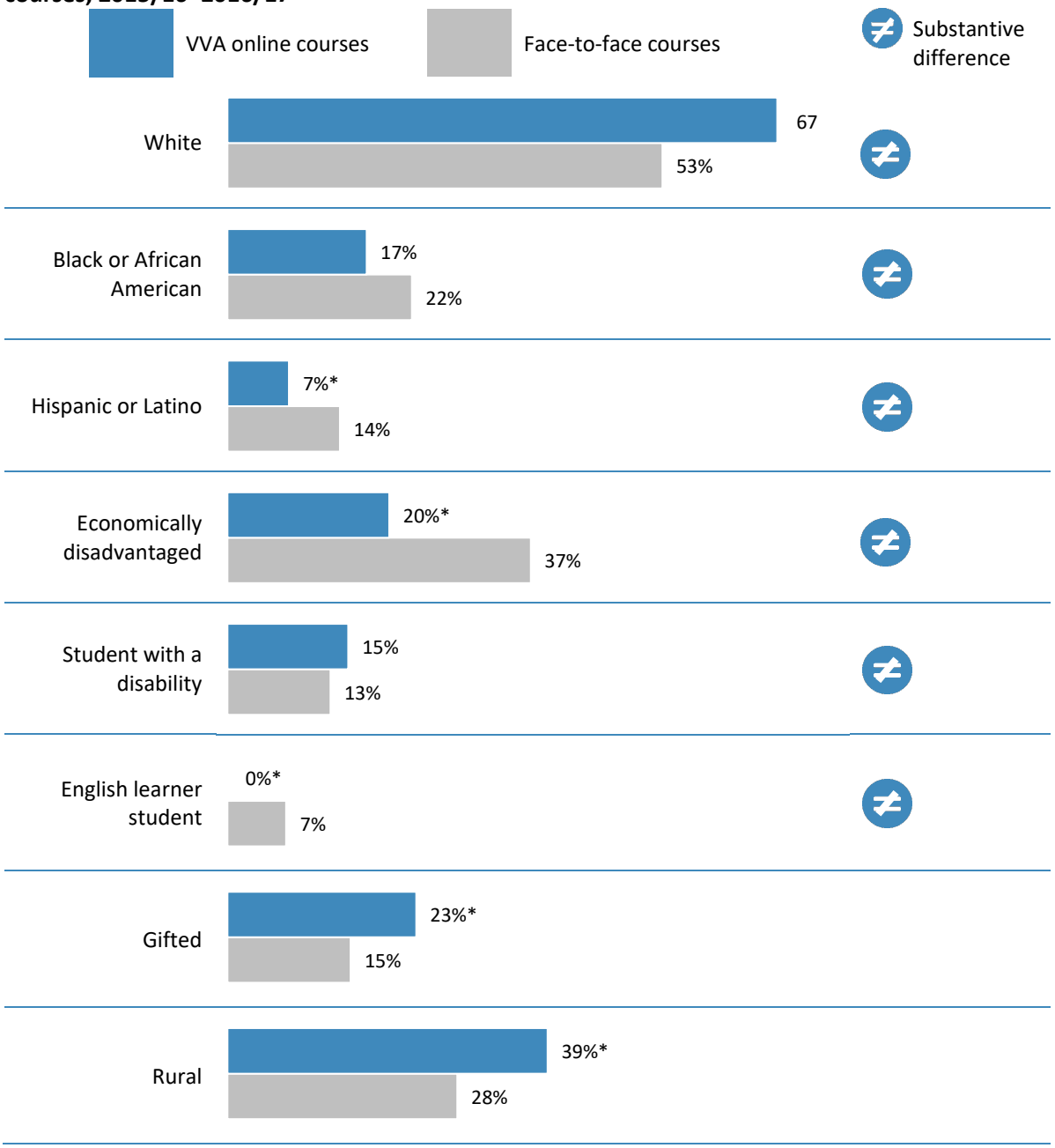
Students in VVA courses who completed SOL or AP exams were more likely to be White and less likely to be Black or Hispanic than their peers in face-to-face courses (exhibits 3 and 4); they were also more likely to be gifted. Students who took core academic courses through VVA and completed SOL exams were also less likely than their face-to-face course peers to be economically disadvantaged or English learner students (exhibit 3). The demographic differences observed may be due to unknown factors influencing students' decisions to take a course online versus face to face, to take the associated end-of-course exam, or both. Racial/ethnic minority students, economically disadvantaged students, students with a disability, and English learner students constituted a small portion of the population for both online and face-to-face AP courses (exhibit 4).

Relative to students in face-to-face courses, more of the students who enrolled in and completed an end-of-course exam through Virtual Virginia resided in rural areas, particularly for Advanced Placement courses.

Some 39 percent of the VVA students who enrolled in and completed an exam in core academic courses resided in a rural locale, compared with 28 percent of face-to-face course students in the study population (exhibit 3). For AP courses, students residing in rural areas represented nearly half the VVA enrollment (46 percent), compared with 20 percent of face-to-face course students in the study population (exhibit 4). For context, the percentage of Virginia students in rural public elementary and secondary schools during the 2015/16 school year was 25 percent.[14] The study findings are consistent with one of Virginia's virtual learning goals: to serve rural students for whom courses may be unavailable due to a lack of highly qualified instructors or too few students to offer the course.

[14] Source: https://nces.ed.gov/pubs2018/2018052/tables/table_04.asp

Exhibit 3. Students who enrolled in a core academic course and completed an end-of-course Standards of Learning exam through Virtual Virginia were demographically different from those in the same face-to-face courses, 2015/16–2016/17

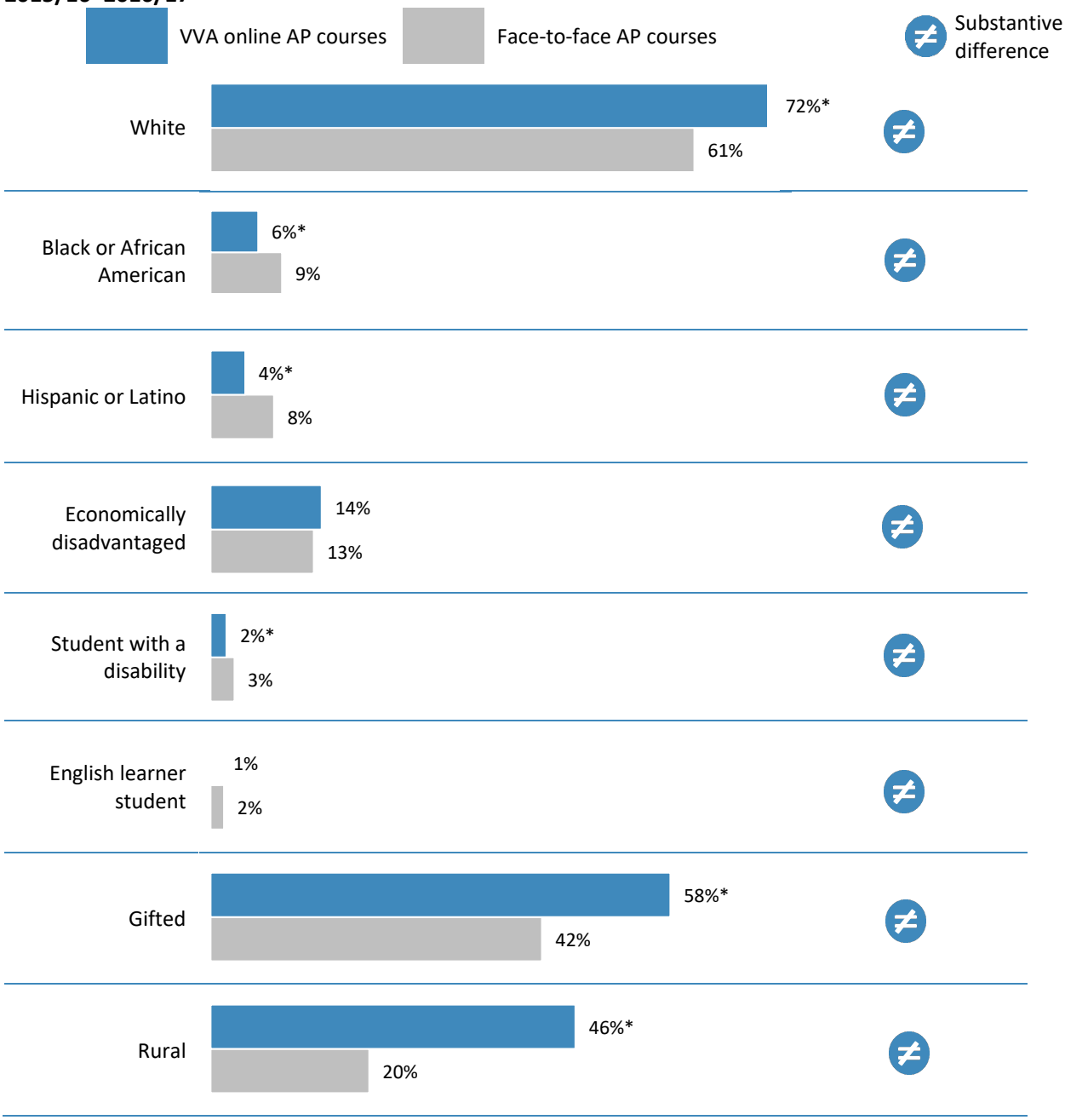


Notes: *N* = 927,211 face-to-face course students with end-of-course SOL exam scores, and *N* = 404 VVA online students with end-of-course SOL exam scores. Hispanic or Latino is defined as a person of Cuban, Mexican, Puerto Rican, South American, Central American or other Spanish culture or origin, regardless of race. Black or African American is defined as a person having origins in any of the black racial groups of Africa. The bars represent the percent of students in each demographic group, for VVA and face-to-face courses. The denominator of each bar is the total number of students who took the SOL exam and enrolled in the course in VVA or face-to-face format. For example, 67 percent of students enrolled in a VVA core course, who also took the SOL for that course, were White.

* Substantively important difference where the effect size (Cox's index) is equal to or greater than 0.25.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit 4. Students who enrolled in an Advanced Placement course and completed an Advanced Placement exam through Virtual Virginia were demographically different from those in the same face-to-face courses, 2015/16–2016/17



Notes: *N* = 214,435 face-to-face course students with AP exam scores, and *N* = 3,396 Virtual Virginia online students with AP exam scores. Hispanic or Latino is defined as a person of Cuban, Mexican, Puerto Rican, South American, Central American or other Spanish culture or origin, regardless of race. Black or African American is defined as a person having origins in any of the black racial groups of Africa. The bars represent the percent of students in each demographic group, for VVA and face-to-face courses. The denominator of each bar is the total number of students who took the AP exam and enrolled in the course in VVA or face-to-face format. For example, 72 percent of students enrolled in a VVA AP course, who also took the AP exam for that course, were White.

* Substantively important difference where the effect size (Cox's index) is equal to or greater than 0.25.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

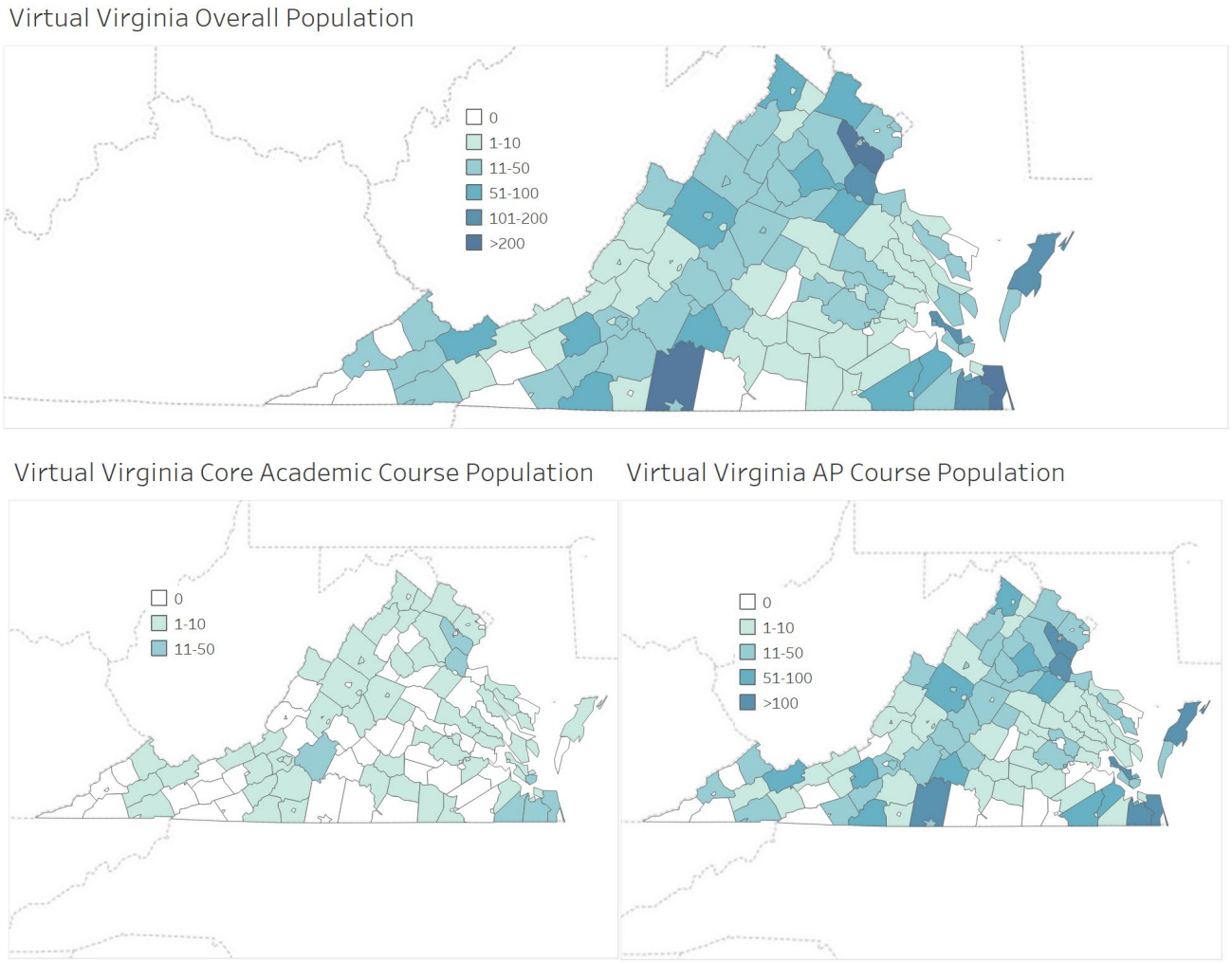
There was some geographic clustering of students in the Virtual Virginia population in more metropolitan areas in parts of the state and in some more rural areas as well.

Students who enrolled in and completed end-of-course exams in VVA were somewhat geographically clustered (exhibit 5). Several of the school divisions with higher numbers of students in the VVA population were located in more metropolitan areas of northern Virginia (Prince William County and Stafford County) and southeast Virginia (Virginia Beach City, Chesapeake County, Hampton City, York County, and Suffolk City). However, there were also several high-use divisions in more rural areas of Virginia (such as Tazewell, Pittsylvania, Patrick, Accomack, and Augusta counties).

Students who enrolled in a Virtual Virginia course and completed the end-of-course exam did so later in their academic trajectory on average than their face-to-face course counterparts.

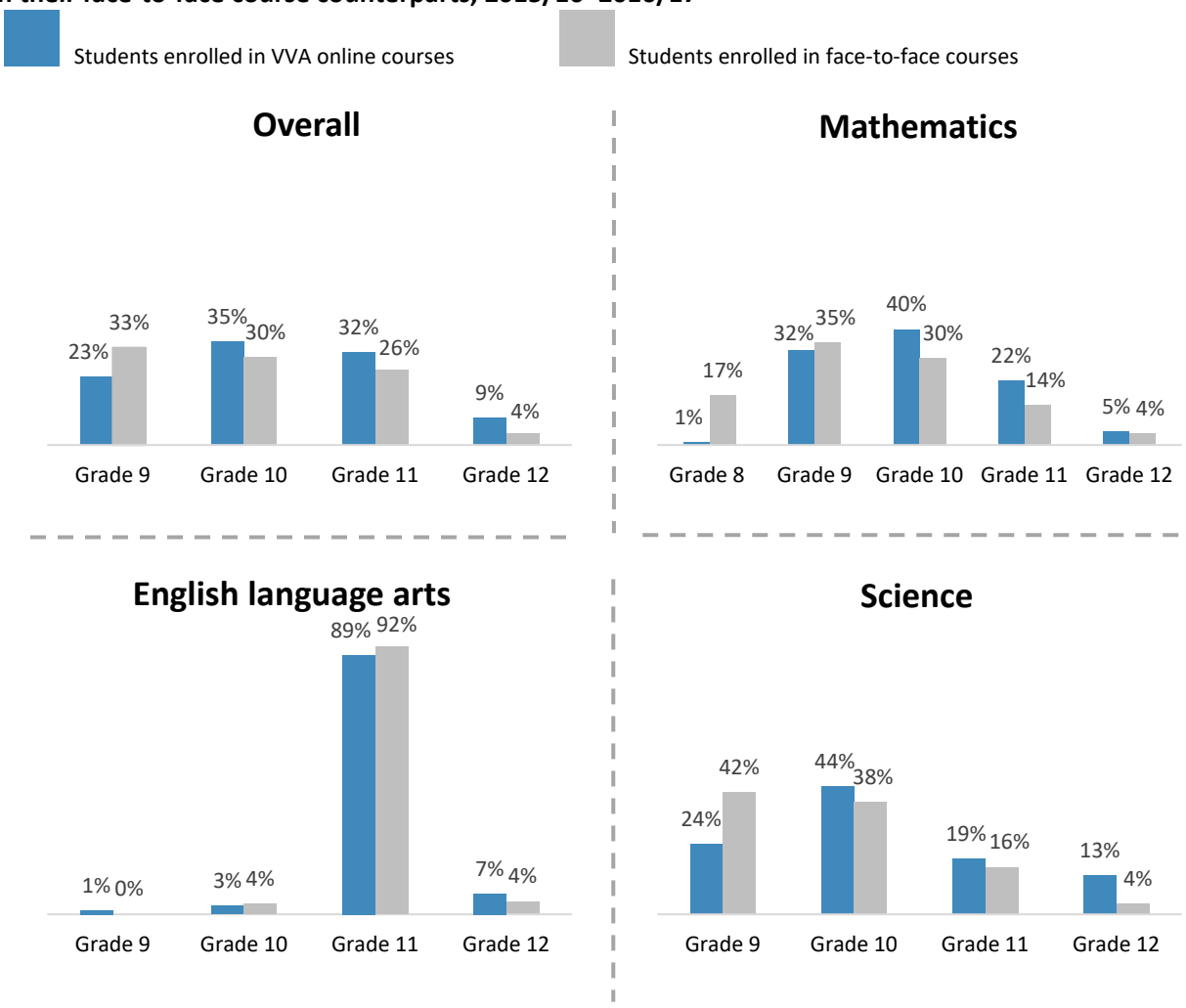
Except for English language arts (English 11 SOL), students enrolled in VVA courses later in their academic trajectory than their face-to-face course counterparts (exhibit 6). For example, only 24 percent of VVA students with end-of-course exam scores in core science courses were in grade 9, compared with 42 percent of face-to-face core science course students. Instead, more of these VVA students were in grade 10 (44 percent versus 38 percent of face-to-face course students). Whereas very few students took the face-to-face course in grade 12 (4 percent), 13 percent of the VVA students were in grade 12. Although it could not be determined reliably from the available data, some students may take VVA courses after failing the course face to face in a prior grade. Providing credit recovery opportunities is one of the most common purposes for offering online courses in K–12 educational settings (Clements, Stafford, Pazzaglia, & Jacobs, 2015; Heppen et al., 2016b; Queen & Lewis, 2011) and may be among Virginia school and division leaders' reasons for offering VVA courses to students.

Exhibit 5. There was some geographic clustering of students who enrolled in a Virtual Virginia course and completed the end-of-course exam, 2015/16–2016/17



Note: The map represents the number of students who both enrolled in Virtual Virginia (VVA) online courses and completed the end of course exam. Virginia school divisions with higher numbers of students in the VVA population are represented by darker shades of blue, while those with lower numbers of students are represented by lighter shades of blue. *N* =401 VVA online students with end-of-course SOL exam scores and *N* = 3,377 VVA online students with end-of-course AP exam scores. Twenty-five VVA online students with end-of-course SOL exam scores did not have school division information and are not included in the map.
Source: Author's analysis of administrative data provided by the Virginia Longitudinal Data System, 2015/16 and 2016/17.

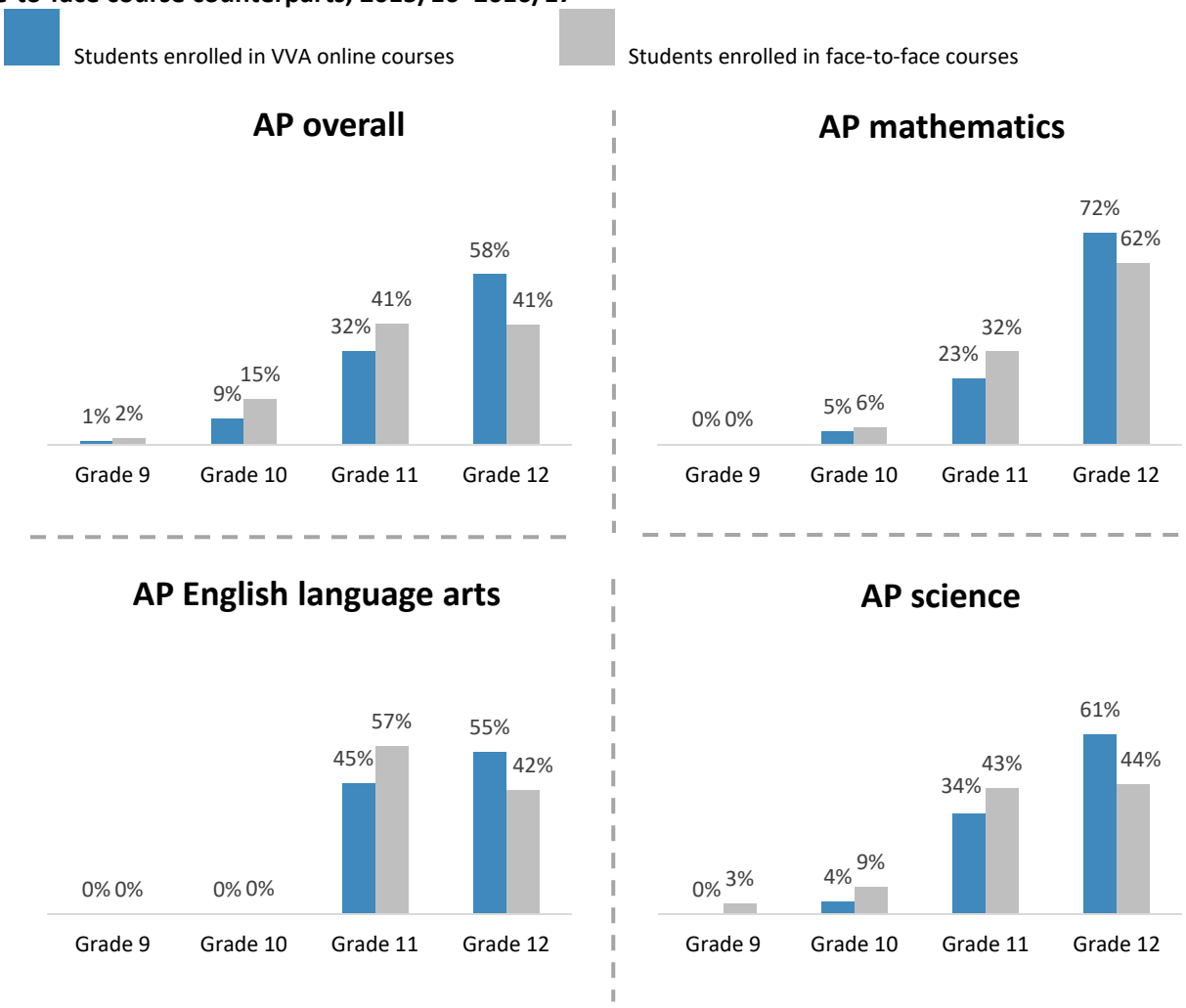
Exhibit 6. Students who enrolled in Virtual Virginia online core academic courses and completed end-of-course Standards of Learning exams took the course in later grades in their academic trajectory on average than their face-to-face course counterparts, 2015/16–2016/17



Note: *Ns* vary by subject. *N* = 927,815 face-to-face course students overall with end-of-course SOL exam scores, and *N* = 430 Virtual Virginia online students overall with end-of-course SOL exam scores. The bars represent the percent of students in each grade, for VVA and face-to-face courses. The denominator of each bar is the total number of students who took the SOL exam and enrolled in the course in VVA or face-to-face format. For example, 23 percent of students enrolled in a VVA core course, who also took the SOL for that course, were in grade 9.
Source**:** Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

For AP courses, grade 12 students constituted more of the VVA population than the face-to-face course population (exhibit 7). For example, 55 percent of face-to-face course students with AP science exam scores were in grades 9, 10, or 11, compared with 38 percent of VVA students with AP exam scores. Nearly two-thirds (61 percent) of the VVA students were taking the AP science course in grade 12, whereas fewer than half (44 percent) of the face-to-face course students were.

Exhibit 7. Students who enrolled in Virtual Virginia online Advanced Placement courses and completed Advanced Placement exams took the course in later grades in their academic trajectory on average than their face-to-face course counterparts, 2015/16–2016/17



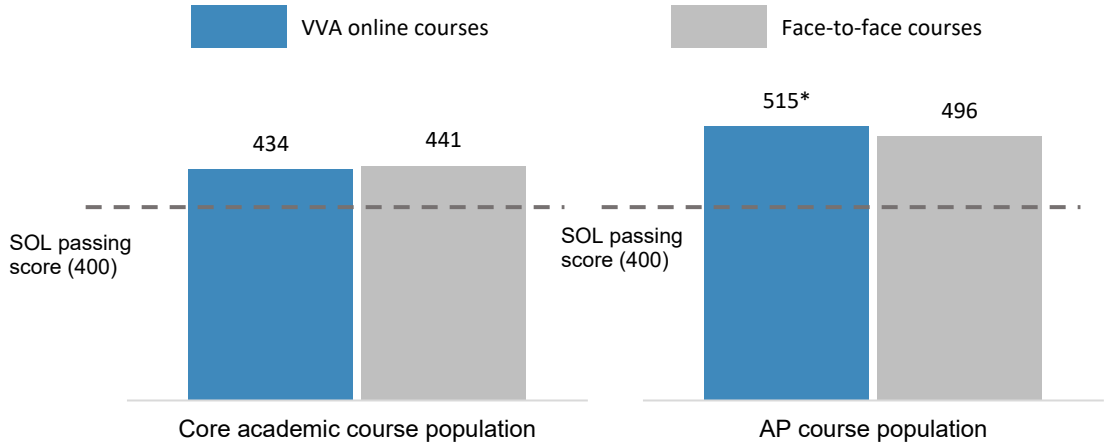
Note: *N*s vary by subject. *N* = 214,435 face-to-face course students overall with AP exam scores, and *N* = 3,396 Virtual Virginia online students overall with AP exam scores. The bars represent the percent of students in each grade, for VVA and face-to-face courses. The denominator of each bar is the total number of students who took the AP exam and enrolled in the course in VVA or face-to-face format. For example, 23 percent of students enrolled in a VVA AP course, who also took the AP exam for that course, were in grade 9.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

On average, students in the Virtual Virginia population earned higher scores on prior measures of their academic achievement than their face-to-face course peers, except for core mathematics courses.

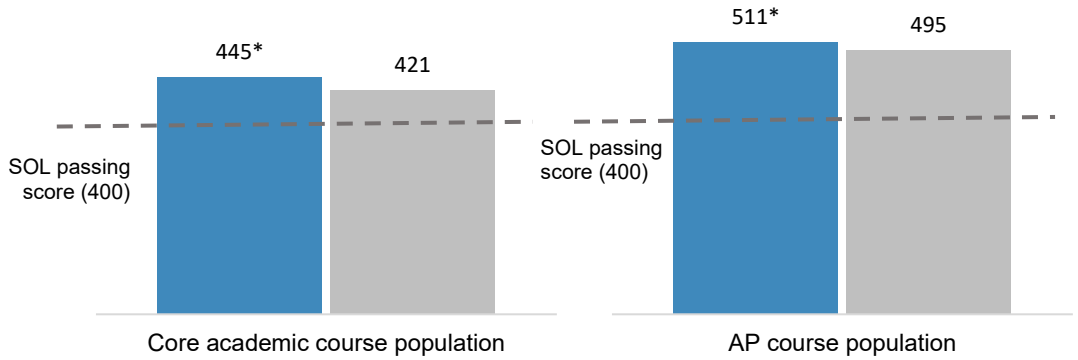
On average, VVA students taking core academic courses and completing end-of-course exams scored higher on the English language arts and science SOL exams they had taken in grade 8 than their face-to-face course peers but lower on mathematics SOL exams (exhibit 8). VVA students also took lower-level mathematics courses in grade 8 than their face-to-face course peers, with 83 percent of VVA students taking grade 8 mathematics, compared with only 56 percent of face-to-face course students (data not shown). Only 13 percent of students in the VVA population took algebra I in grade 8, compared with 29 percent of students in the face-to-face population (data not shown). For AP courses, VVA students scored higher on average than their counterparts on their past SOL exams in math, as well as English language arts and science (exhibit 8).

Exhibit 8. Students who enrolled in courses through Virtual Virginia and completed the associated end-of-course exams typically performed higher on the Standards of Learning exams they took before entering high school than their face-to-face course peers, 2011/12–2015/16

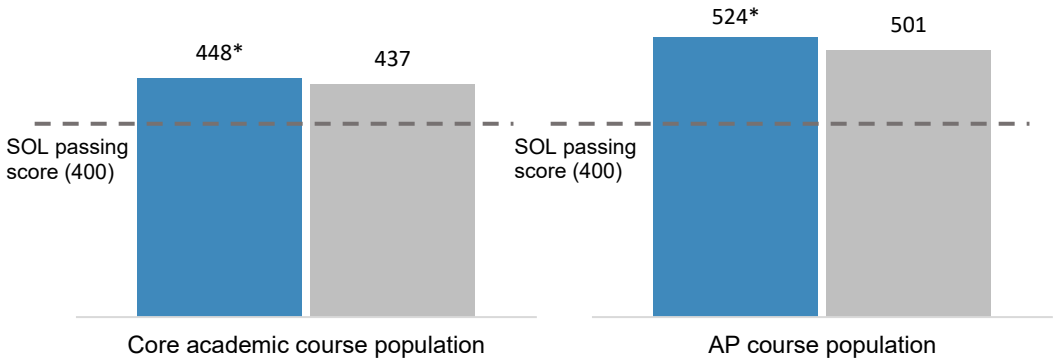
Prior mathematics achievement



Prior English language arts achievement



Prior science achievement



Note: *Ns* vary by subject. Students' prior achievement was measured by their scores on the grade 8 reading SOL for English language arts, the grade 8 science SOL for science, and the mathematics SOL the student took when he or she was in grade 8 (such as grade 8 math or algebra I end-of-course SOL). The prior achievement exam in mathematics varied because of variation in course-taking pathways.
* Substantively important difference where the effect size is equal to or greater than 0.25.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

With the exception of English language arts courses, Virtual Virginia students generally scored lower on end-of-course Standards of Learning and Advanced Placement exams than similar students taking the course face to face.

Students taking VVA courses scored lower on end-of-course SOL and AP exams on average than their face-to-face course counterparts in mathematics and science, after the study team applied statistical controls to account for student demographic characteristics and their prior achievement. The study team observed a similar pattern for AP history courses. These differences were substantively important (exhibit 9). For English language arts, however, students in VVA and face-to-face courses performed similarly on both SOL and AP end-of-course exams.

The size of the difference in average achievement between the online and face-to-face course populations can be quantified in terms of the effect size[15] and change in percentile rank (exhibit 9). For example, an estimated effect size of –0.24 for AP science means that, holding other observed variables constant, a student in the face-to-face course who scored at the 50th percentile on the exam would be predicted to score at the 41st percentile had the student taken the course through VVA (a change in percentile rank of –9).

Exhibit 9. Exam scores were lower in Virtual Virginia courses than in face-to-face courses for most subjects, 2015/16–2016/17

Outcome and subject area	Estimated effect size	Decrease in percentile rank from face-to-face course to VVA course
Core academic courses		
Mathematics SOL	-0.40*	-16
English language arts SOL	-0.05	-2
Science SOL	-0.32*	-13
AP courses		
AP languages	-0.19	-8
AP history/social science	-0.31*	-12
AP science	-0.24	-9
AP English language arts	-0.06	-2
AP mathematics	-0.35*	-14

Note: The expected change in percentile rank for face-to-face course student who scored at the 50th percentile on the exam had the student taken the course through Virtual Virginia.
* Substantively important difference where the effect size is equal to or greater than 0.25.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

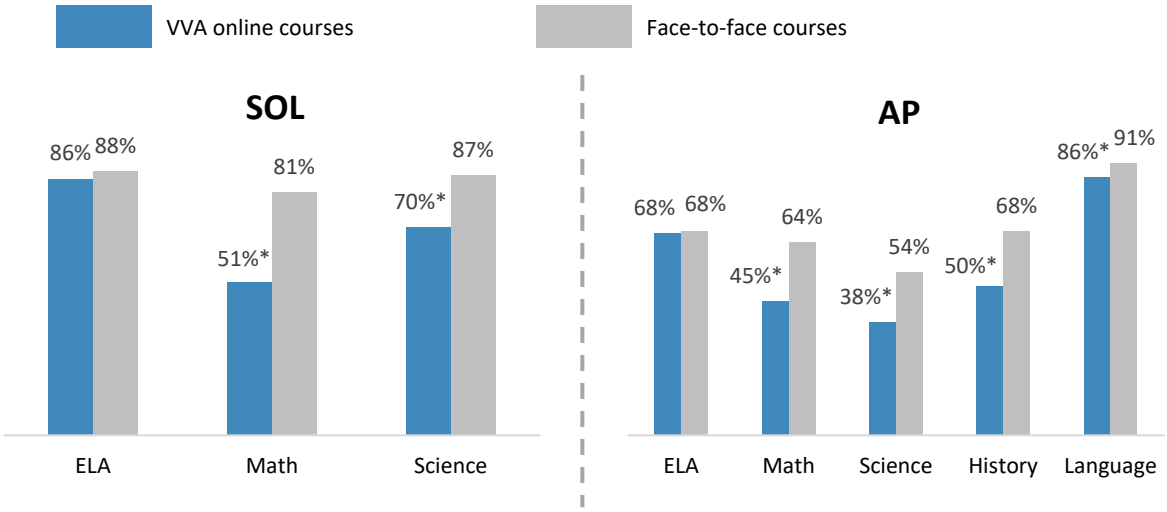
With the exception of English language arts courses, the likelihood of scoring proficient on a Standards of Learning or Advanced Placement exam was lower for students taking the course through Virtual Virginia than for those taking the course face to face.

Students taking VVA courses and completing end-of-course exams appeared to be less likely to earn proficient scores on mathematics and science exams than students taking the course face to face, again after controlling for available student characteristics (exhibit 10). For core academic courses, the difference was largest for mathematics (30 percentage points), followed by science (17 percentage points). No substantively important differences were observed between online and face-to-face course outcomes for English language arts courses.

[15] An effect size is a standardized measure of the magnitude of an effect and is calculated as the standardized mean difference between two groups.

Among AP courses, the difference was largest for AP mathematics (19 percentage points), followed by AP history (18 percentage points), AP science (16 percentage points), and AP languages (5 percentage points). No substantively important differences were observed between online and face-to-face course outcomes for AP English language arts.

Exhibit 10. For most subject areas, the likelihood of attaining a score of proficient or above on the Standards of Learning or Advanced Placement exam was lower for students in Virtual Virginia courses than for students in face-to-face courses, 2015/16–2016/17



Note: The bars represent the predicted percentage chance of attaining a score of 400 or above on an SOL exam or 3 or above on an AP exam, holding constant other factors, such as demographics and prior achievement. In other words, it shows how likely a VVA student is to earn a passing score on the SOL or AP exam compared with a student in a face-to-face course, assuming they have similar background characteristics.
* Substantively important difference where the effect size (Cox's index) is equal to or greater than 0.25.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Limitations

Because the study design was correlational, it is difficult to determine if the differences between online and face-to-face performance are caused by student characteristics, VVA program characteristics, or some other factor such as students' reasons for enrolling in the course or the supports available in their local schools. More evidence and more rigorous and controlled studies, coupled with qualitative studies of VVA implementation, will be needed to further interpret the preliminary findings in this study.

The data used to conduct the analyses were not representative of all VVA enrollments. Not all students who enroll in courses complete them, and online courses often have a higher noncompletion rate than face-to-face courses (Bawa, 2016; Freidhoff, 2016). Additionally, end-of-course SOL exams in Virginia do not cover all courses and subjects (including all VVA courses), and not all students enrolled in courses with end-of-course SOL or AP exams take the exams. In this study, just 48 percent of students enrolling in VVA courses completed the end-of-course exam, compared with 81 percent of students in face-to-face courses. The available administrative data on the reasons for course "withdrawals" prior to test completion are very limited, and the information that is recorded is too unreliable to support a meaningful comparison of students who enroll in VVA but do not complete with those who do. For example, in some cases schools upload an entire roster of students into VVA when they have no face-to-face teacher for the course, and once a teacher is hired, they "withdraw" the students and place them in a face-to-face course.

The population of VVA students was small, particularly for core academic courses, so researchers pooled enrollments into subject areas to increase the available number of online course enrollees. This approach could have masked important differences in outcomes by course and for student subpopulations. Additional research is needed to look more closely at performance among subgroups of students such as economically disadvantaged students, students living in rural areas, English learner students, students taking the course for credit recovery, and students enrolled in VVA's full-time enrollment model.

Lastly—and importantly—VDOE and VVA do not prescribe specifically how students, schools, or school divisions should use VVA. Thus, there is considerable variation in the ways the program is used across the state. For example, 51 percent of all schools with students enrolled in VVA courses also had students enrolled in the same course in a face-to-face format.[16] The reasons students are taking online courses, the kinds of students encouraged to take online courses, and the local supports available to students may contribute to the differences in exam scores (Freidhoff, 2016; Taylor et al., 2016). Such factors could not be measured with the available data. Similarly, this study was not able to address course rigor or instructional quality or the comparability of these across VVA and face-to-face settings. Furthermore, these results may not generalize to online settings other than VVA.

Implications

These analyses demonstrate that students enrolled in core academic and AP online courses through VVA differ, on average, from students in face-to-face courses on measurable characteristics (particularly prior academic achievement) and are also likely to differ on unobserved factors (such as school engagement or academic motivation) that could contribute to differences in their performance on end-of-course exams.

Despite the limitations above, these initial analyses offer some learning and suggestions for next steps. First, this study raised a research question regarding students' academic achievement in VVA courses that could be addressed empirically; documented procedures for processing, cleaning, analyzing, and reporting data in the VLDS to answer the question; and established a methodology that VDOE can replicate to monitor whether the correlational findings hold or change for successive cohorts of students over time. Replicating the regression analyses may be particularly informative if a randomized controlled study of VVA is not feasible. This study may also serve as a roadmap for other states interested in comparing student performance in online and face-to-face courses using data from statewide longitudinal data systems.

Second, the current study provides a rich portrait of who enrolls in VVA online courses and how these students are similar to and different from their peers who take and complete the same course in a face-to-face setting. But the reasons for the observed differences, and how these are related to differences in academic outcomes, remain unknown. Getting a better understanding of why and how students are identified for VVA courses, and the factors that are related to both course completion and end-of-course test taking, such as local supports, would be an important next step for state education leaders to consider. This could include, for example, asking school counselors to report students' reasons for enrolling on the VVA course registration form or surveying students dropping out of VVA courses to understand their reasons for withdrawing. Additional data on selection of and retention in online courses may support more rigorous quasi-experimental study designs. They would also provide

[16] The VLDS does not capture data on which courses were *offered* in a given school, only on which courses had students *enrolled*. Given that courses may be cancelled if take-up is low, or only offered when a particular need arises (for example, a temporarily home-bound student), the difference between offerings and enrollments may be substantial. As such, it is not appropriate to use enrollments as a proxy for offerings.

an opportunity to compare the characteristics of students who enroll in VVA but do not complete with those who do complete.

Lastly, this study focused on only one short-term academic outcome: performance on end-of-course exams. Different relationships may be observed between taking a course online through VVA and other short-term and longer-term outcomes, such as subsequent course-taking patterns and performance, staying on track academically and graduating, or enrolling in college. Future research could also examine whether VVA is an effective way to broaden access to courses that are not available to students at their physical school. Offering online courses in settings where the course is otherwise not available could still be beneficial to the students who take advantage of them, as Heppen et al. (2011) found, even if they underperform relative to students in a face-to-face course.

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Appendices: Comparing the achievement of students in Virtual Virginia and face-to-face courses

The Virginia Department of Education's Virtual Virginia (VVA) program delivers more than 90 online courses to more than 10,000 middle and high school students each year. The department partnered with Regional Educational Laboratory Appalachia to examine the relationship between students' participation in a subset of 31 VVA online courses and their performance on end-of-course Virginia Standards of Learning and Advanced Placement exams during the 2015/16 and 2016/17 school years. These are appendixes to the report *Comparing the achievement of students in Virtual Virginia and face-to-face courses* (Mislevy, Schmidt, Puma, Ezekoye, & Saucedo 2020). They provide details on the data sources, study methodology, and results of sensitivity analyses.

Appendix A: Outcomes, data sources, and methods

This appendix describes in detail the outcome measures used in the analysis, data sources and key terms, data intake and cleaning procedures, and key analysis decisions.

Outcome measures

Given the importance of having comparable outcomes across online and face-to-face courses, the academic achievement outcome of interest was performance on standardized exams, namely the state of Virginia's Standards of Learning (SOL) end-of-course tests and the College Board's Advanced Placement (AP) exams.

Standards of Learning exams

The SOL establish minimum expectations for what Virginia public school students should know and be able to do at the end of each grade or course in English, mathematics, science, history/social science, and other subjects.[17] SOL exams in reading, writing, mathematics, science, and history/social science measure students' success of in meeting the Board of Education's expectations for learning and achievement. Virginia classroom teachers review all items on SOL exams for accuracy and fairness, and teachers also assist the state Board of Education in setting proficiency standards for the tests. A list of all the SOL exams administered in grades 8 through 12 is in exhibit A1.

[17] Source: http://www.doe.virginia.gov/testing/index.shtml

Exhibit A1. Standards of Learning (SOL) exams by grade level

SOL content area	Grade level	
	Grade 8	High school
English: reading	●	●
English: writing	●	●
Mathematics	●	
Science	●	
Algebra I		●
Geometry		●
Algebra II		●
Virginia and U.S. history		●
World history I		●
World history II		●
World geography		●
Earth science		●
Biology		●
Chemistry		●

Source: Virginia Department of Education

SOL exams in English reading, mathematics, science, and history/social science have 35 to 50 items or questions that measure content knowledge, scientific and mathematical processes, reasoning, and critical thinking skills. English writing skills are measured with a two-part exam that has multiple-choice items and an essay. Student performance is graded on a scale of 0 to 600, with 400 representing the minimum level of acceptable proficiency and 500 representing advanced proficiency. The grades 3–8 SOL exams are vertically aligned, while the end-of-course exams (such as the algebra I SOL and geometry SOL) are not.[18] On English reading and mathematics tests, the Board of Education has defined three levels of student achievement—basic, proficient, and advanced—with basic describing progress toward proficiency.

Advanced Placement exams

High schools can choose to offer AP courses developed by the College Board's AP program to allow students to pursue college-level course work in high school. Each course has a corresponding exam, and passing the exam enables high school students to earn college credit for courses they take in high school.

The exams are scored on a scale of 1 to 5. A score of 5 indicates the student is extremely well qualified to receive college credit for that course. A score of 4 means the student is well qualified, and a score of 3 indicates the student is qualified. A score of 2 means the student is possibly qualified, and a score of 1 offers no recommendation for college credit.[19]

Colleges decide what constitutes a passing score on an AP exam, and this can vary depending on the exam's subject matter. Colleges generally give credit for a score of 3 or higher, although more competitive colleges may give

[18] Source: http://www.doe.virginia.gov/boe/accreditation/2017-soa-impact.shtml
[19] Source: https://apstudents.collegeboard.org/about-ap-scores/ap-score-scale-table

credit only for a 4 or higher, depending on the exam.[20] For the purposes of this study, REL Appalachia researchers defined achieving proficiency as earning a score of 3 or higher on an AP exam.

In addition to AP and SOL exam scores, the REL Appalachia study team explored several other academic outcomes with Virginia Department of Education (VDOE) staff and ultimately excluded them from the study because the data were not collected (as was the case for credit attainment), not available within the study time frame (for example, subsequent course enrollment), or not measured consistently across schools/divisions or course format (for example, final grades, incompletes, withdrawals). This is discussed further under "Data intake and cleaning."

Data sources and key terms

REL Appalachia researchers requested student-level data from VDOE via the Virginia Longitudinal Data System (VLDS).[21] Researchers received 14 data files with more than 40 million records across six years. VDOE also provided demographic and academic information on each student, including scores on statewide assessments and AP exams. The specific data that researchers obtained from the VLDS data tables are listed in exhibit A2.

Exhibit A2. Data sources and variables used in analysis

VLDS table	Filters	Data elements used
Student records	2015 and 2016 Grades 8–12	Student demographics Grade level School School division
Student schedules	2015 and 2016 Grades 8–12	Face-to-face course enrollment
State assessment results	2011 through 2016 Grades 7–12	SOL exam scores (outcome and baseline)
AP courses	Grades 9–12	AP exam scores (outcome only)
Virtual Virginia	None	Virtual Virginia course enrollment

Source: Virginia Longitudinal Data System (VLDS)

The analysis also included two variables that were not available from VLDS: locale code and percentage rural. Using the student's school of record from the VLDS, researchers linked the locale classification from the National Center for Education Statistics Common Core of Data and the percentage of the region in which the school was located that was rural from the United States Census.

Definitions for the key terms and variables used in this analysis are in exhibit A3.

Exhibit A3. Definitions of variables and key terms

Term	Definition
City	Comprises three locale codes for territories inside an urbanized area and inside a principal city, as follows: (11) City–Large: 250,000 or more (12) City–Midsize: Less than 250,000 and greater than or equal to 100,000 (13) City–Small: Less than 100,000
Division name	The name of the locality of the school division
Division number	Three-digit state-assigned number for a division that reported the student data to the VDOE

[20] Source: https://apstudents.collegeboard.org/about-ap-scores
[21] Source: http://vlds.virginia.gov/

Term	Definition
Economically disadvantaged	Identifies a student as economically disadvantaged if he or she meets any one of the following: is eligible for free or reduced-price meals, receives Temporary Assistance for Needy Families, is eligible for Medicaid, or identifies as either migrant or experiencing homelessness
English learner	Identifies students who are between 3 and 21 years old, enrolled or preparing to enroll in an elementary or secondary school, and are one of following: • Not born in the United states or whose native languages are not English • Are Native American or Alaska Native, and come from an environment where languages other than English have a significant impact on their level of language proficiency • Migratory, whose native languages are not English, and the dominant languages in the environment where they come from are not English The students must additionally have difficulties speaking, reading, writing, or understanding the English language, which prevent the students' ability to meet the state's proficient level of achievement on state assessments, successfully achieve in classrooms where the language of instruction is English, or participate fully in society
Gender	Identifies the student's gender
Gifted	Those students in public elementary, middle, and secondary schools beginning with kindergarten through grade 12 who demonstrate high levels of accomplishment or who show the potential for higher levels of accomplishment when compared with others of the same age, experience, or environment. Their aptitudes and potential for accomplishment are so outstanding that they require special programs to meet their education needs. These students will be identified by professionally qualified individuals through the use of multiple criteria as having potential or demonstrated aptitudes in one or more of the following areas: general intellectual aptitude; specific academic aptitude; career and technical aptitude; or visual or performing arts aptitude.
Grade	The grade level at which the student receives services in a school or an education institution during a given academic session
Receives special education services	Identifies individuals having a disability and who, by reason thereof, receive special education and related services under the Individuals with Disabilities Education Act (IDEA) according to an individualized education program (IEP), individual family service plan (IFSP), or service plan
Rural	Comprises three locale codes for census-defined rural territories: (41) Rural–Fringe: less than or equal to 5 miles from an urbanized area, as well as rural territory that is less than or equal to 2.5 miles from an urban cluster (42) Rural–Distant: more than 5 miles but less than or equal to 25 miles from an urbanized area, as well as rural territory that is more than 2.5 miles but less than or equal to 10 miles from an urban cluster (43) Rural–Remote: more than 25 miles from an urbanized area and also more than 10 miles from an urban cluster
School name	The name of the school
School number	Four-digit state-assigned number for a school within the school division
Subject	The academic content or subject area (for example, arts, mathematics, reading, or a foreign language) being evaluated
Suburban	Comprises three locale codes for territories outside a principal city and inside an urbanized area: (21) Suburban–Large: 250,000 or more (22) Suburban–Midsize: less than 250,000 and greater than or equal to 100,000 (23) Suburban–Small: less than 100,000
Town	Comprises three locale codes for territories inside an urban cluster: (31) Town–Fringe: less than or equal to 10 miles from an urbanized area (32) Town–Distant: more than 10 miles and less than or equal to 35 miles from an urbanized area (33) Town–Remote: more than 35 miles from an urbanized area

Source: Virginia Longitudinal Data System (VLDS); National Center for Education Statistics. (2019b). *NCES locale codes*. Retrieved from https://nces.ed.gov/programs/handbook/data/pdf/appendix_d.pdf

Data intake and cleaning

This section details the process used to clean and arrange the data for analysis. It is intended to provide enough detail that VDOE or future researchers could replicate the process and produce the same results.

The cleaning proceeded in four stages: creating a demographics dataset for the Virginia student population, creating a course data file, creating an SOL exam scores file, and creating an AP exam scores file.

Creating the demographics dataset

To create the demographics dataset, the team first narrowed the student files to one record per student per year in the outcome years (2015/16 and 2016/17). This entailed four steps: creating analysis variables, dropping records that were duplicates on all analysis and other key variables, dropping students who were not attending Virginia schools at the time of the outcome, and addressing duplicate records in which students appeared in the same year with conflicting values for race, gender, and other demographic variables.

First, the team created a set of analysis variables. The team created a continuous age variable that censored outliers, replacing all ages greater than 22 with the value of 22 and all ages less than 12 with the value of 12 (674 of 3 million records). The team also dichotomized gifted codes into gifted/nongifted and disability types into disability/no disability. Next, the researchers reduced the dataset to the demographic variables used in analysis and dropped any records that were duplicates on all variables, reducing the dataset to 1.3 million records. Inactive students were dropped (that is, those who were previously enrolled but were no longer attending Virginia schools; 164,625 records). Finally, the study team addressed duplicates in which students appeared more than one time in the same year with conflicting values for demographic variables. The prevalence of this issue was usually very low (less than 1 percent of records), except for gifted status (15.6 percent of records) and economically disadvantaged status (5.5 percent of records) (exhibit A4).

Exhibit A4. Students appearing more than one time in the same year with conflicting demographic variables

	Only one value per year	Two or more different values in the same year
Age	986,460	357
	100%	0.04%
Hispanic	986,077	740
	100%	0.07%
Economically disadvantaged status	932,956	53,861
	95%	5.5%
Gifted status	833,268	153,549
	84%	15.6%
English learner	984,785	2,032
	100%	0.2%
Receives special education services	974,299	12,518
	99%	1.3%
Male	986,647	170
	100%	0.02%
Race	985,288	1,529
	100%	0.2%
School number	967,505	19,312
	98%	2.0%
Grade level	976,846	9,971
	99%	1.0%

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

To address the duplicate records with conflicting demographic values, the study team used three approaches. For age, the team created an average-age variable for the 0.04 percent of students who had more than one value for age in the same school year; for sensitivity analyses, the team also kept the maximum and minimum age recorded for the student in the year. For race, ethnicity, economically disadvantaged status, gifted status, English learner status, disability status, and gender (male), the team created a variable that reflected whether the student ever appeared with a "yes" for the variable (if the student was recorded as economically disadvantaged in any record in the year, he or she was recorded as economically disadvantaged for the entire year); again, for sensitivity analyses, the team also kept the inverse of this variable (for example, if a student was ever recorded as not economically disadvantaged in any record in the year, he or she was recorded as not economically disadvantaged for the entire year). Finally, for student race, division, school, and grade level, the team selected the earliest instance in the school year; for sensitivity analyses, the team also kept all later versions.

This first stage of data cleaning returned a Virginia student population dataset of 986,830 students (exhibit A5).

Exhibit A5. Virginia population of students in target study grades, by year and grade level

Grade	2015	2016	Total
8	97,173	97,164	194,337
9	107,568	107,720	215,288
10	101,657	101,670	203,327
11	93,114	95,788	188,902
12	92,594	92,382	184,976
Total	492,106	494,724	986,830

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Creating a course data file

In the second stage, the team created a course data file by combining Virtual Virginia (VVA) and face-to-face courses and removing duplicates in which students appeared more than once in the same course in the same year. The team completed four steps: cleaning face-to-face course files, merging face-to-face courses with the Virginia student population demographics dataset, reading in VVA course files, merging VVA courses with the demographics dataset, and appending the face-to-face and VVA course files.

First, the team cleaned data files containing the course records for grades 8–12 in 2015/16 and 2016/17. After removing duplicates on all variables and reshaping to include one record per student per course per year, the file included approximately 9.5 million records. Next, the team investigated the "credit awarded flag" and "final grade" variables, to determine whether they could be used to indicate whether students had completed the course successfully. Based on prior discussions with VDOE, the team expected that the data quality in these variables would not be sufficient to use them as outcomes. As expected, the credit awarded flag was not available for any records in 2015/16, and 43 percent of records in 2016/17 had conflicting values for this variable in the same course. Likewise, 22 percent of records did not have a final grade for the course, and 10 percent of the records had conflicting values for the final grade. Additionally, the records that did have values for final grade varied greatly in the type of value recorded. For example, some records included letter grades A through F, whereas others had numbers between 0 and 100, and a third group included letter codes reflecting a variety of other outcomes (for example, Meets expectations, Not passed, Satisfactory). Therefore, in consultation with VDOE, the team determined that the course files could not provide a reliable measure for course completion or course grades.

Next, the study team merged the face-to-face courses with the Virginia student population demographics dataset. The quality of the match is shown in exhibit A6. Approximately 7 million course records matched a student in the demographics dataset (76 percent of courses). Another 2.3 million courses did not match to a student in the Virginia student population. However, the majority of these were not the focal courses. In fact, 98 percent of all focal courses merged to the Virginia student population data (2 million records). Finally, 10,613 students in the demographics dataset for the Virginia student population (0.1 percent) did not have a course listed in the course files.

Exhibit A6. Quality of the match between face-to-face courses and Virginia student population dataset

Result	Number of observations	Percent of observations
Not matched overall	2,268,453	23.9
Not matched from courses	2,257,840	23.8
Not matched from Virginia student population	10,613	0.1
Matched	7,225,033	76.1
Total	9,493,486	100

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

The study team retained all records with students in both the Virginia student population and the course file—a total of 7.2 million records. The number of students in each focal course and school year are in exhibit A7.

Exhibit A7. Counts of students, by face-to-face course and school year

Focal course	School Courses for the Exchange of Data (SCED) course code	2015/16	2016/17
English 11	1003	73,374	74,523
Algebra I	2052	102,401	103,383
Algebra II	2056	64,117	67,891
Geometry	2072	92,130	94,470
Earth science I	3001	76,596	78,188
Biology I	3051	103,106	102,742
Chemistry I	3101	64,171	65,718
AP calculus AB	2124	13,590	13,396
AP calculus BC	2125	2,155	2,317
AP computer science A	10157	3,363	3,652
AP statistics	2203	9,021	9.253
AP environmental science	3207	8,385	8,894
AP biology	3056	8,391	9,112
AP physics 1	3165	2,892	5,592
AP physics 2	3166	462	900
AP French language and culture	24114	918	807
AP Latin	24355	519	533
AP Spanish language and culture	24064	2,822	3,065
AP Chinese language and culture	24414	44	143
AP art history	5153	924	901
AP English literature and composition	1006	14,516	13,825
AP English language and composition	1056	2,605	0
AP English language and composition	1005	15,702	17,928
AP human geography	4004	6,757	7,060
AP U.S. history	4104	17,465	18,529
AP world history	4057	11,355	11,449

AP European history	4056	3,893	4,089
AP government and politics: U.S.	4157	17,842	17,620
AP government and politics: comparative	4158	2,794	2,774
AP microeconomics	4203	2,874	2,390
AP macroeconomics	4204	1,387	567
AP psychology	4256	13,172	13,046

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

The study team then imported to Stata (a statistical programming software) files for all VVA courses in 2014/15 and 2015/16. These totaled 31,697 records across the two years. As with the face-to-face courses, the study team investigated the final grade variable in the dataset and found that it was not viable as an outcome. After removing duplicates, this dataset contained 30,868 records. The number of students in each VVA focal course is in exhibit A8.

Exhibit A8. Counts of students, by Virtual Virginia course and school year

Focal course	VVA course ID	2015/16	2016/17
English 11	1150	31	72
Algebra I	3130	32	45
Algebra II	3135	24	75
Geometry	3143	32	90
Earth science I	4210	40	104
Biology I	4310	39	63
Chemistry I	4410	21	58
AP calculus AB	3177	68	95
AP calculus BC	3178	136	82
AP computer science A	3185	62	214
AP statistics	3192	125	138
AP environmental science	4270	350	339
AP biology	4370	125	87
AP physics 1	4570	59	125
AP physics 2	4571	19	39
AP French language and culture	5170	45	36
AP Latin	5370	32	36
AP Spanish language and culture	5570	62	73
AP Chinese language and culture	5860	35	27
AP art history	9151	141	185
AP English literature and composition	1195	150	168
AP English language and composition	1196	118	109
AP human geography	2212	262	258
AP U.S. history	2319	100	143
AP world history	2380	122	106
AP European history	2399	215	192
AP government and politics: U.S.	2445	121	282
AP government and politics: Comparative	2450	133	122
AP microeconomics	2802	224	149
AP macroeconomics	2803	226	149
AP psychology	2902	678	645

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

In the fourth step, researchers merged the VVA courses with the demographics dataset for the Virginia student population. The quality of the merge is shown in exhibit A9. Approximately 97 percent of all VVA records matched to a student in the demographics dataset (30,003 of 30,868). Among students in the focal courses, 98 percent of all records merged. On the other hand, 97 percent of students in the Virginia student population were not enrolled in any VVA courses during either year.

Exhibit A9. Quality of the match between Virtual Virginia courses and the Virginia student population

Result	Number of observations	Percent of observations
Not matched overall	962,570	97.0
Not matched from VVA courses	865	0.1
Not matched from Virginia student population	961,705	96.9
Matched	30,003	3.0
Total	992,573	100

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Finally, the study team appended the VVA course files with the face-to-face courses and investigated the proportion of students taking two courses in the same subject in the same year. A total of 4,787 records appeared twice, once in face-to-face course and once in VVA files. This amounted to 0.2 percent of all records but 46 percent of VVA courses. After consultation with VDOE, the study team determined that students enrolled in both course types should be marked as participating in VVA for the course. In this step, the study team also dropped any courses that were marked as "virtual" in the course file but were not in the VVA file. (Those records represented virtual courses from other providers.)

The enrollment for each focal course is shown in exhibit A10.

Exhibit A10. Proportion of students enrolled in face-to-face, Virtual Virginia, or both course types, by focal course

Focal course	Face to face	VVA	Both (counted as VVA)
AP art history	978	129	100
AP biology	16,525	86	80
AP calculus AB	25,576	70	66
AP calculus BC	4,393	140	50
AP Chinese	126	45	8
AP computer science	6,512	79	116
AP English language	31,918	140	55
AP English literature	26,885	89	132
AP environmental science	15,798	233	274
AP European history	6,753	199	121
AP French	789	65	9
AP government and politics: comparative	5,352	110	78
AP government and politics: U.S.	32,185	123	148
AP human geography	11,960	186	189
AP Latin	508	44	17
AP macroeconomics	1,564	142	114
AP microeconomics	4,881	126	130
AP physics 1	8,409	121	37
AP physics 2	4,089	50	6
AP psychology	24,042	522	446
AP Spanish	2,986	91	27

Focal course	Face to face	VVA	Both (counted as VVA)
AP statistics	17,056	132	89
AP U.S. history	34,167	83	99
AP world history	22,577	95	79
Algebra I	196,953	28	28
Algebra II	127,794	61	34
Biology	196,562	24	57
Chemistry	124,440	29	36
Earth science	144,355	32	75
English 11	140,149	25	54
Geometry	157,890	47	52
Total	1,394,172	3,346	2,806

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

After narrowing the file to the focal courses, the final course file included 1.4 million course records, with 770,375 unique students.

Creating a file for Standards of Learning test scores

In the third stage, the study team created a clean file of student test scores on the SOL exams. This stage proceeded in three steps. First, the study team imported to the statistical analysis software Stata the 2015/16 and 2016/17 SOL scores for students in grades 8 through 12. The 2015/16 file included 1.7 million records, and the 2016/17 file 1.6 million. However, approximately 3 percent of students appeared more than once in the same test in the same year, with different scores. To address these duplicates, the study team removed records of the student retaking the same test by ordering the records by test date and keeping the score associated with the earliest test date as the main variable for the analysis. The team also imported to Stata the files of test scores for students in grade 8 in 2011/12 through 2014/15 and cleaned and deduplicated them in the same way as the 2015/16 and 2016/17 data files. This file included only grade 8 students because it served as the baseline measure for students who took focal courses in later years.

Second, the researchers merged the SOL exam datasets with the course files. Between 64 and 78 percent of all courses and SOLs matched (exhibit A11).

Exhibit A11. Quality of the match between Standards of Learning test files and course files

	SOL did not match to a course	Course did not match to an SOL	SOL and courses matched
Mathematics	107,311	112,040	394,139
	17%	18%	65%
English language arts	65,514	9,071	133,174
	32%	4%	64%
Science	80,726	42,340	427,269
	15%	8%	78%

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

In the third step of this stage, the study team arranged the SOL datasets to associate the appropriate outcome and prior achievement for each focal course. This is discussed further under "Key analysis decisions."

Finally, researchers examined the remaining duplicates: 3.5 percent of students took more than one course in the same subject area in the same year. They determined that this was caused by students in block-scheduled schools

who could take more than one focal course in the same year but in different semesters. These duplicates were retained.

Creating a clean file for Advanced Placement test scores

In the final stage of data cleaning, the study team created a clean file of student test scores on the AP exams. This stage proceeded in four steps. First, the study team imported to Stata the AP scores for students in grades 9 through 12. The full file included 269,565 records, but it was stored as a "wide" file, with 163 variables corresponding to each test subject date and outcome. The researchers reshaped the file to provide one line per student per test. Then they identified cases where students took the same AP exam more than once and retained only the earliest test score (to eliminate retests). After this deduplication, only tests that were associated with the 2015/16 and 2016/17 school years were retained. The final file included 273,866 records.

In the second step of this stage, the study team merged the AP exam data with the Virginia student population demographics dataset. Nearly all AP exam records (98 percent) merged to a student in the Virginia student population. However, approximately 76 percent of all students in the Virginia student population were not linked to an AP exam.

In the third step, the researchers merged the AP file with the course data. Most AP exams (82 percent) were matched to student course files. However, 18 percent of all AP exams could not be linked to courses in the same year. After consultation with VDOE, we determined that this mismatch was legitimate because students are allowed to take the AP exams without enrolling in the course. These records were dropped, however, as they could not be linked to the independent variable of interest (VVA versus face-to-face course-taking).

In the fourth step, the study team arranged the AP datasets to associate the appropriate outcome and prior achievement for each focal course (discussed further under "Key analysis decisions"). Finally, the team examined the proportion of students who took more than one AP course in the same subject area in the same year. Given the number of AP courses grouped within each area, this was common, particularly in the history and social science. As with the SOL outcome, the team determined that these duplicates were legitimate and retained all records. In the main analysis, each of these records was treated as independent. In a sensitivity analysis, we examined the mean score by subject area as the outcome.

Summarizing the final study population of end-of-course exam completers

The final study population consisted of all Virginia public school students in grades 8–12 who enrolled in focal courses with either end-of-course SOL or AP exams during the 2015/16 and 2016/17 school years and completed the exam (exhibits A12 and A13).

Exhibit A12. Final study population for core academic courses with end-of-course Standards of Learning exams

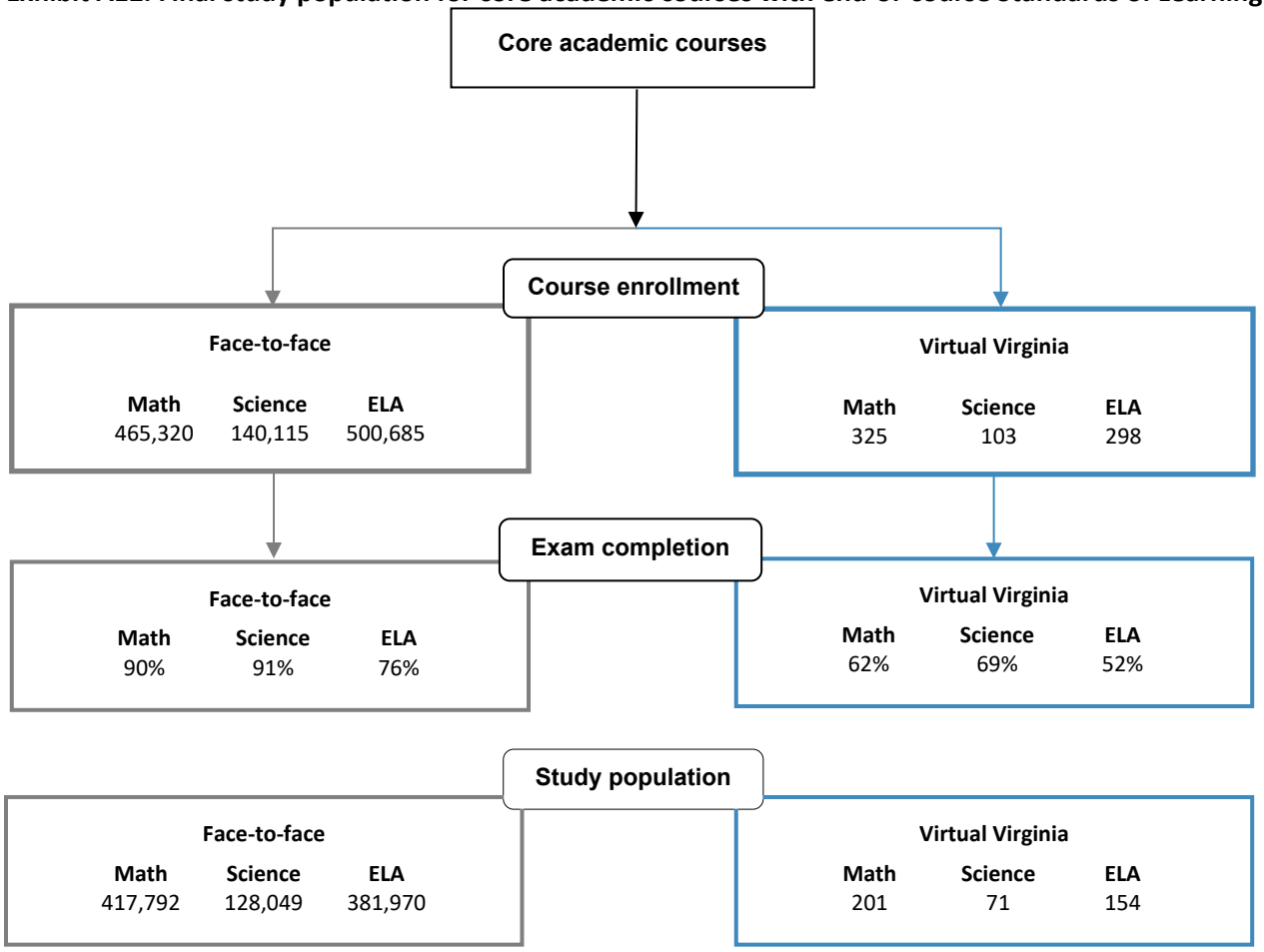
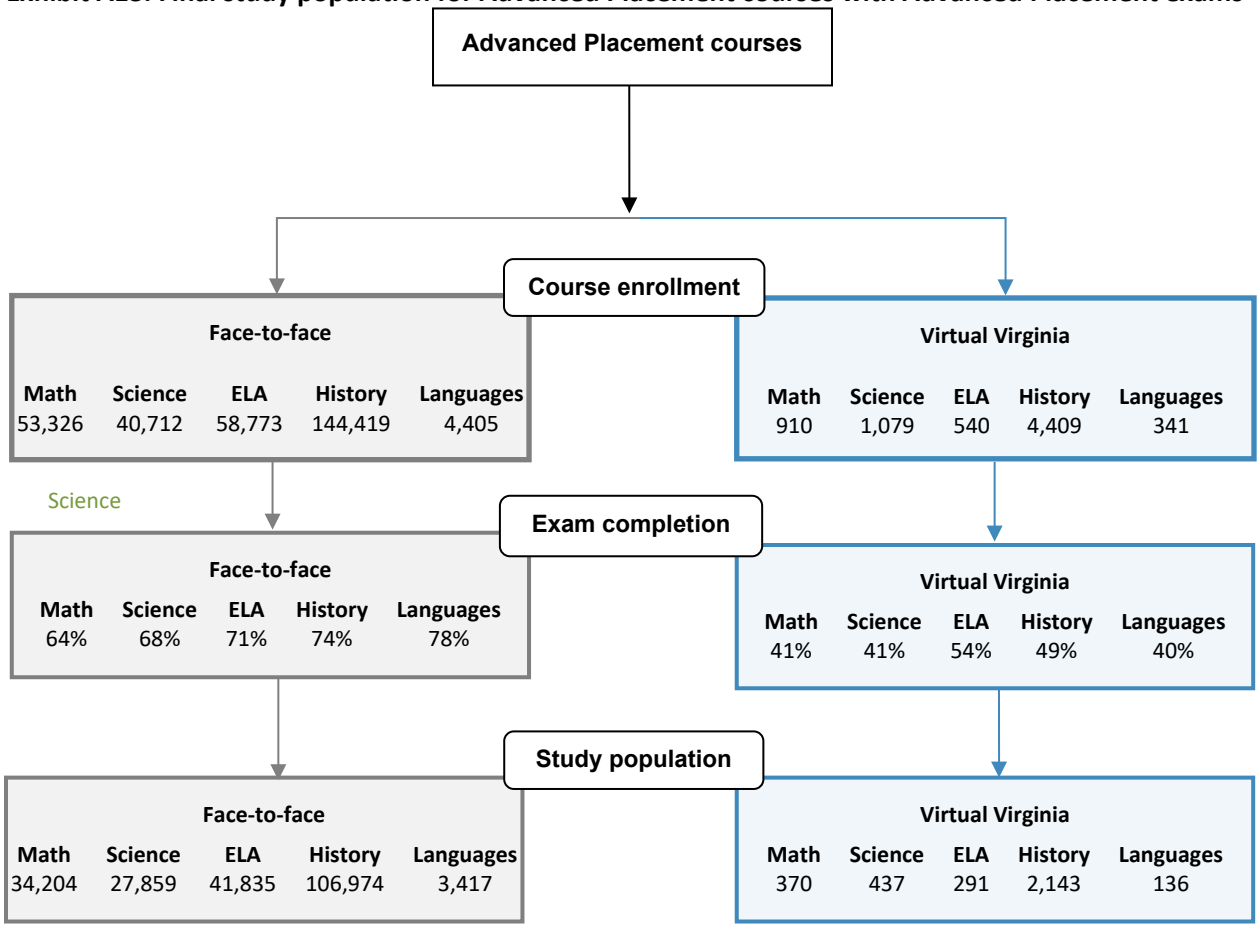


Exhibit A13. Final study population for Advanced Placement courses with Advanced Placement exams



Key analysis decisions

The four key analysis decisions were the choice of outcome and baseline tests to be used, the grouping of courses into subject area domains, the approach to imputation, and the model specifications.

Outcome and baseline tests used in the analysis

In consultation with the VDOE, the study team selected the outcome tests shown in exhibit A14 for the SOL outcomes. The researchers allowed the baseline achievement test to vary in mathematics because of variation in course-taking pathways and outcome grade levels. For example, if a student took algebra I in grade 8, his or her baseline score may be the grade 7 mathematics exam. On the other hand, if a student took algebra I in grade 9, his or her baseline score may be the grade 8 mathematics exam. To account for the variation in course-taking pathways, the models controlled for baseline exam and outcome exam, as well as for baseline school year, outcome year, and outcome grade level.

Exhibit A14. Crosswalk between focal core academic courses and their Standards of Learning outcomes and baseline measures

Course name	Virtual Virginia course	SCED course code	Outcome test	Baseline test
English 11	1150	1003	Reading	Grade 8 reading
Algebra I	3130	2052	Algebra I	Grade 7 mathematics
		2061		Grade 8 mathematics
Geometry	3143	2072	Geometry	Grade 7 mathematics
				Grade 8 mathematics
				Algebra I
Algebra II	3135	2056	Algebra II	Grade 7 mathematics
				Grade 8 mathematics
				Algebra I
				Geometry
Earth science	4210	3001	Earth science	Grade 8 science
Biology	4310	3051	Biology	
Chemistry I	4410	3101	Chemistry	

Source: Virginia Department of Education

Likewise, in consultation with VDOE, the study team selected the SOL exams shown in exhibit A15 to use as baseline achievement for the AP outcomes (the outcome was always the AP exam that corresponded to the course). As with SOLs, the mathematics baseline measure was allowed to vary depending on the student's course-taking pathway.

Exhibit A15. Crosswalk between focal Advanced Placement courses and their Standards of Learning baseline measures

Area	Course name	SOL exam code Pretest	SOL exam name Pretest
English	AP English literature	108	Grade 8 reading
	AP English language		
Math	AP calculus AB	127	Grade 7 math
	AP calculus BC	137	
	AP computer science A	128	Grade 8 math
		138	
		120	Algebra I
	AP statistics	121	Geometry
		122	Algebra II
Sciences	AP environmental science	5	
	AP biology	58	Grade 8 science
	AP physics 1	165	
	AP physics 2		
Languages	AP French	108	Grade 8 reading
	AP Latin		
	AP Spanish		
	AP Chinese		
History and social science	AP human geography	108	Grade 8 reading
	AP U.S. history		
	AP world history		
	AP European history		
	AP government and politics: U.S.		
	AP government and politics: comparative		
	AP microeconomics		
	AP macroeconomics		
	AP psychology		
	AP art history		

Source: Virginia Department of Education

The study team combined test scores within a subject area to examine the relationship between taking a course online through VVA and SOL outcomes because too few students were taking the individual VVA courses to power an analysis at the course level. Because the analysis combines both outcome and baseline scores across multiple tests, which were not vertically aligned, the team standardized the test scores by test and year. In this approach, the study team created *z*-scores by subtracting the mean from each test score and dividing it by the standard deviation. Researchers commonly use this approach to put different tests on a comparable metric or scale (for example, Clark, Isenberg, Liu, Makowsky, & Zukiewicz, 2014). Therefore, students in this analysis were compared with one another based on their relative position in the distribution of scores for the same test in the same year.

Grouping courses into subject area domains

The 24 focal AP courses and seven focal SOL courses fall into five subject area domains: English, mathematics, sciences, languages, and history and social science (exhibit A16).

Exhibit A16. Focal courses, by subject area domain

Subject area	AP course name	Core academic course name
English	AP English literature	English 11
	AP English language	
Math	AP calculus AB	Algebra I
	AP calculus BC	Geometry
	AP computer science A	Algebra II
	AP statistics	
Sciences	AP environmental science	Earth science
	AP biology	Biology
	AP physics 1	Chemistry
	AP physics 2	
Languages	AP French	
	AP Latin	
	AP Spanish	
	AP Chinese	
History and social science	AP human geography	
	AP U.S. history	
	AP world history	
	AP European history	
	AP government and politics: U.S.	
	AP government and politics: comparative	
	AP microeconomics	
	AP macroeconomics	
	AP psychology	
	AP art history	

Source: Virginia Department of Education

Imputing for missing values

Imputing for missing files was done separately for the AP and the SOL exam outcomes files. The SOL exam outcomes file had a total of 144,168 students with an SOL outcome score and no SOL baseline score. The incomplete records were spread across subjects, with the most missing in chemistry and the fewest missing in earth science (exhibit A17).

Exhibit A17. Number and percentage of records missing baseline scores in the Standards of Learning dataset, by test subject

Subject	Number missing (percent)
Algebra I	19,939 (14)
Algebra II	13,295 (12)
Biology	29,979 (16)
Chemistry	27,711 (23)
Earth science	13,715 (11)
English 11	20,818 (16)
Geometry	18,711 (14)

Total	144,168 (15)

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Demographics were also missing for some students, but the prevalence was much lower: Demographic information was missing for only 717 students who had SOL outcomes scores, and in all cases all demographic variables were missing, including the school and division. These represent the small group of students who appeared in course and test files but did not appear in the demographics dataset.

The AP exam outcomes file contained a total of 27,962 students with an AP outcome score and no SOL baseline score, and 27,890 were missing their baseline school year (exhibit A18). No demographic variables were missing for students who had AP outcomes.

Exhibit A18. Number and percentage of records missing baseline scores in the Advanced Placement dataset, by test subject

Subject	Number missing (percent)
Art history	72 (11)
Biology	2,857 (25)
Calculus AB	1,691 (11)
Calculus BC	351 (10)
Chinese	25 (16)
Computer science	573 (11)
English language	2,721 (11)
English literature	2,157 (12)
Environmental science	2,927 (27)
European history	493 (10)
French	81 (12)
Government and politics – comparative	379 (12)
Government and politics – U.S.	2,739 (12)
Human geography	1,032 (12)
Latin	38 (10)
Macroeconomics	176 (10)
Microeconomics	375 (11)
Physics 1	1,175 (19)
Psychology	1,938 (10)
Spanish	316 (13)
Statistics	1,204 (11)
U.S. history	2,806 (11)
World history	1,764 (9)
Total	27,890 (14)

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Imputation in each dataset proceeded in two steps. First, logical imputation was used for missing school year and grade level at baseline. The study team assumed an on-time grade progression and counted backward from the outcome year or grade level to establish the baseline year or grade level.

In the second step, the researchers used multiple imputation to impute for the remaining missing values. The team used the "mi impute" command in Stata, which triggers an iterative Markov Chain Monte Carlo method to impute missing values (StataCorp, 2009, p. 145). Economic disadvantage, gifted status, disability status, and

gender (male) were imputed using logistic regression; age and baseline scores were imputed using linear regression; and race was imputed using multinomial regression. These missing values were imputed based on the following variables: outcome test score, outcome school year, outcome grade level, pretest school year, pretest grade level, course subject, school, division, and a flag for enrollment in a VVA course. The team used a flag for enrollment in a VVA course rather than imputing separately for the two groups because of the small population size. This approach is approved under the What Works Clearinghouse version 4.0 standards (U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, What Works Clearinghouse, 2017).

The team imputed only for demographics and baseline test scores, not for outcome scores. The team made this choice for two reasons. First, the population of interest for the analysis was students who completed the focal courses and took the end-of-course exam. As discussed, it was not possible to determine course completion from the course files. Accordingly, the team limited the population to students who completed the course and took the associated exam. Second, the imputation of outcomes would have been impractical, given that the analysis allowed the baseline test to vary depending on student course progression in mathematics. That is, if a student appeared in the file with a score on the algebra I assessment in grade 8, it was impossible to know if he or she should have been assessed in geometry in grade 9 or 10, as students varied in the course pathways they followed.

Unadjusted student outcomes in Virtual Virginia courses

As a precursor to the analysis, the study team examined the unadjusted student test scores and passing rates for students in VVA courses by course subject area. The results of this analysis are in exhibit A19.

Exhibit A19. Unadjusted student outcomes in Virtual Virginia courses

Subject area	Mean scaled score	Percent proficient	Number of enrollments
SOL			
Math	411.6	55%	154
Science	433.4	76%	201
ELA	449.6	87%	71
AP			
Math	2.9	59%	370
Science	2.6	49%	437
ELA	3.1	71%	291
History and social science	3.0	61%	2,143
Languages	3.6	83%	136

Notes: Percent proficient is the percentage of students who scored a 400 or above on the SOL exam or a 3 or above on the AP exam.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Model specifications

In this study, three methodological approaches were used to address the research question. First, descriptive statistics were used to examine unadjusted differences in the characteristics of students taking VVA and completing end-of-course exams and students with exam scores in comparable face-to-face courses. The findings related to student demographic characteristics and prior achievement were produced from this approach.

Second, the study team used multivariate ordinary least squares regressions to examine the relationship between VVA and end-of-course SOL and AP exam scores while controlling for the influence of available student characteristics. These regressions aggregated exam scores across courses. For example, algebra I, geometry, and

algebra II SOL exam scores contributed to the "mathematics SOL" outcome. Because these exams are not scored on the same basis, the team used *z*-scores to create a common outcome metric. This transformation allowed for comparing student test results with one another based on their relative position in the distribution of all scores for the same test in the same year. Unlike descriptive statistics, multivariate regressions partially account for preexisting differences between students by factoring out the relationship between these background characteristics and student achievement outcomes. The linear regressions took the following form:

$$y = \beta_0 + \beta_1 VirtualVirginia + \beta_2 \boldsymbol{X} + \beta_3 \boldsymbol{C} + \beta_4 \boldsymbol{Yr} + \beta_4 PctRural + \beta_5 \boldsymbol{M} + e$$

where *y* is the continuous *z*-score for the outcome in each subject area (for example, mathematics SOLs), *VirtualVirginia* is an indicator for whether the student took the course as a part of VVA (1/0), *X* is a vector of student characteristics (grade level, age, gender, race, gifted status, English learner, disability status, economically disadvantaged status), *C* is a series of indicators for each outcome course (for example, algebra I and algebra II in the mathematics model, with geometry as the comparison group) and baseline course (for example, mathematics 8 and algebra I in the mathematics model, with mathematics 7 as the comparison group) included in the model, *Yr* is a series of indicators for each outcome and baseline year, *PctRural* is a continuous variable for the percentage of the population in the region of the school that is designated as rural, and *M* is a series of indicators for which student-level variables were imputed using multiple imputation. The errors were clustered at the school level using Stata's "cluster" command.

Finally, the study team used multivariate logistic regression to predict whether a student reached proficiency (a score of 400 or above on an SOL exam or 3 or above on an AP exam). Logistic regression estimates the relationship between one or more variables and a binary outcome—one that has only two possible results (proficient or not proficient). These regressions also combine outcomes across courses, and partially account for preexisting differences between students. These models used the same series of control variables as in the linear regressions.

In accordance with guidance from the Institute of Education Sciences, REL Appalachia researchers did not conduct statistical significance testing because the study data cover the entire population of interest. Statistical tests are typically meant to make inferences about a population when the data cover only a sample from that population. When data come from a census, there is no statistical uncertainty in descriptive findings (with some exceptions, such as when data are missing). Differences between groups in the data are, in fact, the true differences in the population.

REL Appalachia researchers used the criterion set by the What Works Clearinghouse (WWC, 2017) to determine the substantive importance of the differences in outcomes or characteristics between the students in VVA and face-to-face courses: an effect size—a standardized measure of the magnitude of the difference—of 0.25 or greater. For continuous outcomes such as test scores, the WWC has adopted the most commonly used effect size index, the standardized mean difference known as Hedges' *g*. The WWC's effect size measure of choice for dichotomous outcomes is the Cox index, which yields effect size values similar to the values of Hedges' *g*. These effect size indices increase in magnitude as the difference between the groups on the outcome measure get larger; however, Cox's index also increases as proportions approach 0 or 1.

Appendix B: Detailed analysis results

This appendix provides the full results for analyses discussed in the main report. Presented are three types of exhibits: descriptive exhibits (page B-1), full model results for the Standards of Learning (SOL) outcomes (page B-10), and full model results for the Advanced Placement (AP) outcomes (page B-16).

Descriptive exhibits

Information on the demographics and baseline achievement of students in the study by exam type (SOL or AP) and course subject area are in exhibits B1–B10. Three types of baseline achievement are shown: *z*-scores, scaled scores, and percentage proficient or advanced. Z-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.

SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The means of this population usually fall in the proficient range, with the average baseline for some AP courses in the advanced range.

The percentage of students proficient or advanced was derived directly from the SOL scaled scores, as described above. The majority of students in this population scored proficient on their baseline SOL exam, with a larger proportion of the students with AP outcomes falling into the advanced category.

Standards of Learning courses

Exhibit B1. Descriptive statistics on student demographics and baseline scores, all Standards of Learning courses

Characteristic	Students who take the SOL exam		
	Overall	VVA	Face to face
Grade 8	7%	0%	7%
Grade 9	33%	23%	33%
Grade 10	30%	35%	30%
Grade 11	26%	32%	26%
Grade 12	4%	9%	4%
Native American	0%	0%	0%
Asian	6%	2%	6%
Black or African American	22%	17%	22%
Hispanic	14%	7%	14%
White	53%	67%	53%
Pacific Islander	0%	0%	0%
Multiple races	4%	5%	4%
Male	50%	38%	50%
Age	15.5	15.9	15.5
Economically disadvantaged	37%	20%	37%
Gifted	15%	23%	15%
English learner	7%	0%	7%
Receives special education services	13%	15%	13%
Region percent rural	54	47	54

Characteristic	Students who take the SOL exam		
	Overall	VVA	Face to face
Baseline SOL *z*-score	0.01	0.19	0.01
Baseline SOL scaled score	436.5	443.1	436.5
Baseline SOL percent proficient or advanced	77	85	77
Baseline SOL percent advanced	11	16	11
Number of students	928,237	426	927,811

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B2. Descriptive statistics on student demographics and baseline scores, Standards of Learning mathematics courses

Characteristic	Students who take the SOL exam		
	Overall	VVA	Face to face
Grade 8	17%	1%	17%
Grade 9	35%	32%	35%
Grade 10	30%	40%	30%
Grade 11	14%	22%	14%
Grade 12	4%	5%	4%
Native American	0%	0%	0%
Asian	7%	1%	7%
Black or African American	22%	19%	22%
Hispanic	14%	10%	14%
White	52%	64%	52%
Pacific Islander	0%	0%	0%
Multiple races	5%	5%	4%
Male	49%	41%	49%
Age	15.5	15.6	15.2
Economically disadvantaged	36%	20%	36%
Gifted	15%	21%	15%
English learner	7%	0%	7%
Receives special education services	11%	16%	11%
Region percent rural	54	48	54
Baseline SOL *z*-score	0.01	-0.05	0.01
Baseline SOL scaled score	441.1	434.5	441.1
Baseline SOL percent proficient or advanced	81	86	81
Baseline SOL percent advanced	12	13	12
Number of students	382,124	154	381,970

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B3. Descriptive statistics on student demographics and baseline scores, Standards of Learning English language arts courses

Characteristic	Students who take the SOL exam		
	Overall	VVA	Face to face
Grade 8	0%	0%	0%
Grade 9	0%	1%	0%
Grade 10	4%	3%	4%
Grade 11	92%	89%	92%
Grade 12	4%	7%	4%
Native American	0%	0%	0%
Asian	5%	0%	5%
Black or African American	25%	11%	25%
Hispanic	13%	8%	13%
White	52%	72%	52%
Pacific Islander	0%	0%	0%
Multiple races	4%	5%	4%
Male	55%	34%	55%
Age	15.5	16.7	16.7
Economically disadvantaged	40%	20%	40%
Gifted	11%	12%	11%
English learner	8%	0%	8%
Receives special education services	16%	20%	16%
Region percent rural	53	42	53
Baseline SOL *z*-score	0.01	0.46	0.01
Baseline SOL scaled score	420.8	445.3	420.8
Baseline SOL percent proficient or advanced	67	85	67
Baseline SOL percent advanced	7	10	7
Number of students	128,120	71	128,049

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B4. Descriptive statistics on student demographics and baseline scores, Standards of Learning science courses

Characteristic	Students who take the SOL exam		
	Overall	VVA	Face to face
Grade 8	0%	0%	0%
Grade 9	42%	24%	42%
Grade 10	38%	44%	38%
Grade 11	16%	19%	16%
Grade 12	4%	13%	4%
Native American	0%	0%	0%
Asian	6%	4%	6%
Black or African American	22%	18%	22%
Hispanic	13%	6%	13%
White	53%	68%	53%
Pacific Islander	0%	1%	0%
Multiple races	4%	5%	4%
Male	50%	38%	50%
Age	15.5	15.9	15.5
Economically disadvantaged	37%	19%	37%
Gifted	16%	28%	16%
English learner	7%	1%	7%
Receives special education services	13%	12%	13%
Region percent rural	55	48	55
Baseline SOL *z*-score	0.01	0.25	0.01
Baseline SOL scaled score	437.0	448.2	437.0
Baseline SOL percent proficient or advanced	76	84	76
Baseline SOL percent advanced	11	20	11
Number of students	417,993	201	417,792

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement courses

Exhibit B5. Descriptive statistics on student demographics and baseline scores, all Advanced Placement courses

Characteristic	Students who take the AP exam		
	Overall	VVA	Face to face
Grade 9	2%	1%	2%
Grade 10	15%	9%	15%
Grade 11	41%	32%	41%
Grade 12	41%	58%	41%
Native American	0%	0%	0%
Asian	17%	13%	17%
Black or African American	9%	6%	9%
Hispanic	8%	4%	8%
White	61%	72%	61%
Pacific Islander	0%	0%	0%
Multiple races	5%	4%	5%
Male	44%	44%	44%
Age	16.8	17.0	16.8
Economically disadvantaged	13%	14%	13%
Gifted	42%	58%	42%
English learner	2%	1%	2%
Receives special education services	3%	2%	3%
Region percent rural	52	58	52
Baseline SOL *z*-score	0.10	0.42	0.10
Baseline SOL scaled score	493.1	513.9	492.7
Baseline SOL percent proficient or advanced	98	99	98
Baseline SOL percent advanced	41	57	41
Number of students	217,848	3,396	214,452

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B6. Descriptive statistics on student demographics and baseline scores, Advanced Placement mathematics courses

Characteristic	Students who take the AP exam		
	Overall	VVA	Face to face
Grade 9	0%	0%	0%
Grade 10	6%	5%	6%
Grade 11	32%	23%	32%
Grade 12	62%	72%	62%
Native American	0%	0%	0%
Asian	21%	15%	22%
Black or African American	7%	5%	7%
Hispanic	7%	4%	7%
White	60%	70%	60%
Pacific Islander	0%	1%	0%
Multiple races	5%	6%	5%
Male	53%	59%	53%
Age	17.1	17.2	17.1
Economically disadvantaged	10%	10%	10%
Gifted	48%	67%	48%
English learner	2%	1%	2%
Receives special education services	3%	1%	3%
Region percent rural	52	55	52
Baseline SOL *z*-score	0.08	0.35	0.08
Baseline SOL scaled score	495.7	515.2	495.5
Baseline SOL percent proficient or advanced	99	99	99
Baseline SOL percent advanced	43	58	43
Number of students	34,574	370	34,204

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B7. Descriptive statistics on student demographics and baseline scores, Advanced Placement English language arts courses

Characteristic	Students who take the AP exam		
	Overall	VVA	Face to face
Grade 9	0%	0%	0%
Grade 10	0%	0%	0%
Grade 11	57%	45%	57%
Grade 12	42%	55%	42%
Native American	0%	0%	0%
Asian	15%	11%	15%
Black or African American	10%	7%	10%
Hispanic	7%	5%	7%
White	62%	72%	62%
Pacific Islander	0%	0%	0%
Multiple races	5%	4%	5%
Male	37%	37%	37%
Age	17.0	17.0	17.0
Economically disadvantaged	12%	13%	12%
Gifted	41%	57%	41%
English learner	1%	0%	1%
Receives special education services	3%	1%	3%
Region percent rural	55	59	55
Baseline SOL *z*-score	0.16	0.43	0.15
Baseline SOL scaled score	495.1	510.7	495.0
Baseline SOL percent proficient or advanced	98	99	98
Baseline SOL percent advanced	43	53	43
Number of students	42,126	291	41,835

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B8. Descriptive statistics on student demographics and baseline scores, Advanced Placement science courses

Characteristic	Students who take the AP exam		
	Overall	VVA	Face to face
Grade 9	3%	0%	3%
Grade 10	9%	4%	9%
Grade 11	43%	34%	43%
Grade 12	45%	61%	44%
Native American	0%	0%	0%
Asian	19%	11%	19%
Black or African American	9%	6%	9%
Hispanic	7%	3%	8%
White	59%	75%	59%
Pacific Islander	0%	0%	0%
Multiple races	5%	5%	5%
Male	43%	43%	43%
Age	16.8	17.1	16.8
Economically disadvantaged	13%	14%	13%
Gifted	43%	55%	43%
English learner	2%	1%	2%
Receives special education services	3%	4%	3%
Region percent rural	46	57	45
Baseline SOL *z*-score	0.07	0.38	0.06
Baseline SOL scaled score	501.1	524.3	500.7
Baseline SOL percent proficient or advanced	99	100	99
Baseline SOL percent advanced	47	67	47
Number of students	28,296	437	27,859

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B9. Descriptive statistics on student demographics and baseline scores, Advanced Placement history and social science courses

Characteristic	Students who take the AP exam		
	Overall	VVA	Face to face
Grade 9	3%	2%	3%
Grade 10	26%	11%	26%
Grade 11	38%	31%	38%
Grade 12	33%	56%	33%
Native American	0%	0%	0%
Asian	15%	12%	15%
Black or African American	10%	6%	10%
Hispanic	8%	4%	8%
White	62%	73%	61%
Pacific Islander	0%	0%	0%
Multiple races	5%	4%	5%
Male	44%	42%	44%
Age	16.6	16.9	16.5
Economically disadvantaged	13%	14%	13%
Gifted	40%	57%	40%
English learner	2%	1%	2%
Receives special education services	4%	2%	4%
Region percent rural	53	59	53
Baseline SOL *z*-score	0.09	0.42	0.08
Baseline SOL scaled score	490.0	511.9	489.5
Baseline SOL percent proficient or advanced	98	100	97
Baseline SOL percent advanced	39	55	38
Number of students	109,117	2,143	106,974

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B10. Descriptive statistics on student demographics and baseline scores, Advanced Placement languages courses

Characteristic	Students who take the AP exam		
	Overall	VVA	Face to face
Grade 9	1%	0%	1%
Grade 10	12%	17%	12%
Grade 11	37%	36%	37%
Grade 12	51%	47%	51%
Native American	0%	1%	0%
Asian	17%	35%	16%
Black or African American	4%	4%	4%
Hispanic	27%	4%	28%
White	47%	49%	47%
Pacific Islander	0%	1%	0%
Multiple races	4%	6%	4%
Male	37%	40%	36%
Age	16.9	16.8	17.0
Economically disadvantaged	20%	21%	20%
Gifted	45%	57%	44%
English learner	9%	7%	9%
Receives special education services	3%	3%	3%
Region percent rural	48	47	49
Baseline SOL *z*-score	0.18	0.60	0.16
Baseline SOL scaled score	483.8	518.3	482.5
Baseline SOL percent proficient or advanced	94	98	94
Baseline SOL percent advanced	39	61	38
Number of students	3,553	136	3,417

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Full model results for Standards of Learning outcomes

The coefficients (estimates) and standard errors for all variables included in the models used to estimate the relationship between taking a course online through Virtual Virginia (VVA) and SOL exam outcomes are in exhibits B11–B13. The first row of each exhibit displays the coefficient of interest: the relationship between VVA and the test outcome. Subsequent rows display each of the control variables in the model and the number of enrollments in that model. These models counted number of enrollments rather than number of students because a student may have been enrolled in more than one course in a subject area. (Appendix C presents the results of a sensitivity test aggregating results to the student level.)

Standards of Learning test scores

This section includes the linear regression results estimating the relationship between VVA and SOL *z*-scores.

Exhibit B11. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes – Mathematics

	Estimate	SE
Virtual Virginia course	-0.40	0.04
Baseline score	0.47	<0.01
Grade 9	-0.31	0.03
Grade 10	-0.37	0.04
Grade 11	-0.43	0.06
Grade 12	-0.44	0.08
Outcome test is algebra II	<0.01	0.02
Outcome test is geometry	0.14	0.02
Outcome year is 2016/17	0.03	0.02
Student age	-0.10	<0.01
Male	-0.02	<0.01
Black/African American	-0.14	0.01
Hispanic	-0.05	0.01
Asian	0.19	0.01
Economically disadvantaged	-0.12	0.01
Gifted	0.27	0.01
English learner	<0.01	0.01
Receives special education services	-0.13	0.01
Pretest is algebra I	0.50	0.03
Pretest is geometry	0.80	0.04
Pretest is mathematics 8	0.09	0.03
Pretest year is 2012	0.08	0.02
Pretest year is 2013	0.20	0.04
Pretest year is 2014	0.32	0.05
Pretest year is 2015	0.34	0.07
District percent rural	-0.09	0.02
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.09	0.20
Imputed for English learner status	-0.98	0.21
Imputed for baseline score	0.10	0.01
Constant	-0.26	0.02
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, z-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average z-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B12. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes – English language arts

	Estimate	SE
Virtual Virginia course	-0.05	0.03
Baseline score	0.58	0.01
Grade 10	0.23	0.07
Grade 11	0.45	0.07
Grade 12	0.39	0.07
Outcome year is 2016/17	0.02	0.02
Student age	-0.16	0.01
Male	-0.01	<0.01
Black/African American	-0.19	0.01
Hispanic	-0.03	0.01
Asian	0.01	0.02
Economically disadvantaged	-0.14	0.01
Gifted	0.27	0.01
English learner	-0.24	0.02
Receives special education services	-0.23	0.01
Pretest year is 2012	0.08	0.03
Pretest year is 2013	0.08	0.04
Pretest year is 2014	0.10	0.06
Pretest year is 2015	0.55	0.14
District percent rural	-0.06	0.02
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.01	0.25
Imputed for English learner status	-0.77	0.28
Imputed for baseline score	-0.07	0.01
Constant	0.05	0.04
Number of enrollments		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B13. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes – Science

	Estimate	SE
Virtual Virginia course	-0.32	0.03
Baseline score	0.61	0.01
Grade 10	0.18	0.01
Grade 11	0.20	0.03
Grade 12	0.30	0.04
Outcome test is chemistry	-0.21	0.01
Outcome test is earth science	0.19	0.01
Outcome year is 2016/17	-0.03	0.01
Student age	-0.13	<0.01
Male	-0.01	<0.01
Black/African American	-0.18	0.01
Hispanic	-0.07	0.01
Asian	0.14	0.01
Economically disadvantaged	-0.13	0.01
Gifted	0.30	0.01
English learner	-0.11	0.01
Receives special education services	-0.19	0.01
Pretest year is 2012	0.19	0.02
Pretest year is 2013	0.30	0.03
Pretest year is 2014	0.38	0.04
Pretest year is 2015	0.44	0.05
District percent rural	-0.07	0.01
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.17	0.37
Imputed for English learner status	-0.56	0.38
Imputed for baseline score	<0.01	0.01
Constant	-0.05	0.01
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Standards of Learning proficiency

The logistic regression results estimating the relationship between VVA and proficiency on the SOL exam (a score of 400 or higher) are in exhibits B14–B16.

Exhibit B14. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes – Mathematics

	Estimate	SE
Virtual Virginia course	-1.42	0.14
Baseline score	1.52	0.02
Grade 9	-0.74	0.10
Grade 10	-0.68	0.12
Grade 11	-0.49	0.15
Grade 12	-0.17	0.19
Outcome test is algebra II	0.90	0.06
Outcome test is geometry	0.23	0.05
Outcome year is 2016/17	-0.28	0.05
Student age	-0.32	0.01
Male	-0.09	0.01
Black/African American	-0.51	0.04
Hispanic	-0.18	0.04
Asian	0.45	0.04
Economically disadvantaged	-0.42	0.02
Gifted	0.98	0.04
English learner	-0.09	0.03
Receives special education services	-0.59	0.03
Pretest is algebra I	0.86	0.11
Pretest is geometry	0.93	0.15
Pretest is mathematics 8	0.44	0.10
Pretest year is 2012	0.27	0.06
Pretest year is 2013	0.62	0.10
Pretest year is 2014	0.88	0.13
Pretest year is 2015	1.20	0.18
District percent rural	-0.25	0.06
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.37	0.57
Imputed for English learner status	-1.45	0.64
Imputed for baseline score	-0.04	0.02
Constant	-0.54	0.07
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B15. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes – English language arts

	Estimate	SE
Virtual Virginia course	-0.21	0.12
Baseline score	2.21	0.02
Grade 10	0.77	0.18
Grade 11	1.62	0.19
Grade 12	1.64	0.22
Outcome year is 2016/17	-0.10	0.06
Student age	-0.52	0.02
Male	-0.02	0.02
Black/African American	-0.62	0.04
Hispanic	0.04	0.04
Asian	0.22	0.06
Economically disadvantaged	-0.52	0.02
Gifted	1.38	0.14
English learner	-0.87	0.05
Receives special education services	-1.04	0.03
Pretest year is 2012	-0.20	0.09
Pretest year is 2013	-0.18	0.13
Pretest year is 2014	-0.27	0.19
Pretest year is 2015	0.98	0.53
District percent rural	-0.19	0.05
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.10	0.76
Imputed for English learner status	-1.15	0.82
Imputed for baseline score	-0.33	0.04
Constant	0.55	0.15
Number of enrollments		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0-399 means a student did not pass the test. A score of 400-499 means a student passed a test and was classified as proficient, and a score of 500-600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B16. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes – Science

	Estimate	SE
Virtual Virginia course	-1.08	0.09
Baseline score	2.21	0.02
Grade 10	0.87	0.05
Grade 11	1.34	0.09
Grade 12	1.94	0.13
Outcome test is chemistry	-0.06	0.04
Outcome test is earth science	0.18	0.04
Outcome year is 2016/17	-0.29	0.04
Student age	-0.49	0.01
Male	0.04	0.01
Black/African American	-0.69	0.03
Hispanic	-0.25	0.03
Asian	0.45	0.04
Economically disadvantaged	-0.53	0.02
Gifted	1.58	0.08
English learner	-0.57	0.04
Receives special education services	-0.90	0.02
Pretest year is 2012	0.21	0.08
Pretest year is 2013	0.63	0.10
Pretest year is 2014	1.02	0.13
Pretest year is 2015	1.29	0.16
District percent rural	-0.05	0.04
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.66	0.53
Imputed for English learner status	-0.62	0.55
Imputed for baseline score	-0.04	0.04
Constant	0.12	0.03
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0-399 means a student did not pass the test. A score of 400-499 means a student passed a test and was classified as proficient, and a score of 500-600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Full model results for Advanced Placement outcomes

This section shows the coefficients (estimates) and standard errors for all variables included in the models used to estimate the relationship between VVA and AP exam outcomes. The first row displays the coefficient of interest: the relationship between VVA and the test outcome. Subsequent rows display each of the control variables in the model and the number of enrollments in that model. These models count number of enrollments rather than number of students because a student may have been enrolled in more than one course in a subject area. (Appendix C presents the results of a sensitivity test aggregating results to the student level.)

Advanced Placement test scores

The linear regression results estimating the relationship between VVA and AP *z*-scores are in exhibits B17–B21.

Exhibit B17. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes – Mathematics

	Estimate	SE
Virtual Virginia course	-0.34	0.07
Baseline score	0.39	0.01
Grade 10	-0.06	0.11
Grade 11	-0.12	0.14
Grade 12	-0.01	0.16
Outcome test is calculus AB	-0.12	0.05
Outcome test is calculus BC	-0.31	0.05
Outcome test is computer science	-0.34	0.07
Outcome year is 2016/17	-0.03	0.02
Student age	-0.14	0.02
Male	0.13	0.01
Black/African American	-0.31	0.03
Hispanic	-0.15	0.03
Asian	0.02	0.03
Economically disadvantaged	-0.21	0.03
Gifted	0.19	0.02
English learner	0.09	0.05
Receives special education services	0.12	0.04
Pretest is algebra I	0.42	0.04
Pretest is geometry	0.82	0.06
Pretest year is 2013	0.09	0.04
Pretest year is 2014	0.31	0.07
Pretest year is 2015	0.35	0.20
District percent rural	-0.11	0.06
Imputed for baseline score	<0.01	0.06
Constant	-0.43	0.06
Number of enrollments		
Virtual Virginia	296	
Face to face	29,846	
Total	30,142	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B18. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes – English language arts

	Estimate	SE
Virtual Virginia course	-0.06	0.07
Baseline score	0.40	0.01
Grade 10	0.59	0.58
Grade 11	0.80	0.62
Grade 12	1.23	0.64
Outcome subject is English language	0.31	0.13
Outcome year is 2016/17	-0.04	0.02
Student age	-0.11	0.01
Male	-0.04	0.01
Black/African American	-0.34	0.03
Hispanic	-0.11	0.02
Asian	0.14	0.03
Economically disadvantaged	-0.29	0.02
Gifted	0.39	0.02
English learner	-0.10	0.05
Receives special education services	-0.03	0.03
Pretest year is 2013	0.06	0.03
Pretest year is 2014	0.06	0.23
Pretest year is 2015	0.26	0.53
District percent rural	-0.19	0.05
Imputed for baseline score	0.26	0.02
Constant	-0.17	0.06
Number of enrollments		
Virtual Virginia	291	
Face to face	41,835	
Total	42,126	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B19. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes – Science

	Estimate	SE
Virtual Virginia course	-0.24	0.07
Baseline score	0.47	0.01
Grade 10	0.46	0.12
Grade 11	0.49	0.12
Grade 12	0.62	0.13
Outcome test is biology	0.19	0.05
Outcome test is environmental science	0.29	0.06
Outcome year is 2016/17	0.04	0.03
Student age	-0.12	0.01
Male	0.18	0.02
Black/African American	-0.41	0.03
Hispanic	-0.18	0.03
Asian	-0.02	0.03
Economically disadvantaged	-0.21	0.02
Gifted	0.28	0.02
English learner	0.15	0.05
Receives special education services	0.01	0.03
Pretest year is 2013	0.02	0.03
Pretest year is 2014	0.08	0.06
Pretest year is 2015	0.13	0.10
District percent rural	-0.21	0.06
Imputed for baseline score	0.05	0.03
Constant	-0.16	0.04
Number of enrollments		
Virtual Virginia	437	
Face to face	27,859	
Total	28,296	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B20. Full model output for the relationship between Virtual Virginia and Advanced Placement score outcomes – History and social science

	Estimate	SE
Virtual Virginia course	-0.31	0.05
Baseline score	0.40	0.01
Grade 10	0.32	0.09
Grade 11	0.48	0.10
Grade 12	0.55	0.11
Outcome test is art history	-0.07	0.10
Outcome test is European history	-0.02	0.06
Outcome test is comparative government	0.01	0.07
Outcome test is U.S. government	-0.06	0.06
Outcome test is human geography	0.14	0.05
Outcome test is macroeconomics	-0.34	0.10
Outcome test is microeconomics	-0.22	0.08
Outcome test is psychology	0.07	0.06
Outcome test is U.S. history	-0.07	0.06
Outcome year is 2016/17	0.01	0.02
Student age	-0.10	0.01
Male	0.13	0.01
Black/African American	-0.31	0.03
Hispanic	-0.13	0.02
Asian	0.13	0.03
Economically disadvantaged	-0.27	0.02
Gifted	0.34	0.01
English learner	-0.03	0.03
Receives special education services	-0.01	0.02
Pretest year is 2013	-0.02	0.02
Pretest year is 2014	-0.01	0.04
Pretest year is 2015	-0.01	0.08
District percent rural	-0.14	0.05
Imputed for baseline score	0.19	0.01
Constant	0.04	0.04
Number of enrollments		
Virtual Virginia	2,143	
Face to face	106,974	
Total	109,117	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B21. Full model output for the relationship between Virtual Virginia and Advanced Placement score outcomes – Languages

	Estimate	SE
Virtual Virginia course	-0.19	0.18
Baseline score	0.28	0.02
Grade 11	-0.09	0.20
Grade 12	-0.04	0.22
Outcome test is Chinese	-0.19	0.16
Outcome test is French	0.08	0.09
Outcome test is Latin	-0.02	0.13
Outcome year is 2016/17	-0.12	0.19
Student age	-0.16	0.04
Male	-0.02	0.04
Black/African American	-0.25	0.08
Hispanic	0.61	0.06
Asian	0.11	0.11
Economically disadvantaged	-0.03	0.06
Gifted	0.14	0.04
English learner	0.36	0.07
Receives special education services	-0.27	0.08
Pretest year is 2013	-0.26	0.14
Pretest year is 2014	-0.16	0.22
Pretest year is 2015	-0.08	0.24
District percent rural	-0.19	0.11
Imputed for baseline score	0.33	0.05
Constant	-0.05	0.11
Number of enrollments		
Virtual Virginia	136	
Face to face	3,417	
Total	3,553	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement proficiency

The logistic regression results estimating the relationship between VVA and AP proficiency (a score of 3 or higher) are in exhibits B22–B26.

Exhibit B22. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes – Mathematics

	Estimate	SE
Virtual Virginia course	-0.81	0.18
Baseline score	0.87	0.03
Grade 10	-0.68	1.03
Grade 11	-0.76	1.13
Grade 12	-0.49	1.18
Outcome test is calculus AB	0.18	0.11
Outcome test is calculus BC	0.70	0.12
Outcome test is computer science	0.04	0.16
Outcome year is 2016/17	-0.21	0.05
Student age	-0.29	0.05
Male	0.28	0.03
Black/African American	-0.71	0.09
Hispanic	-0.35	0.07
Asian	0.04	0.07
Economically disadvantaged	-0.51	0.07
Gifted	0.42	0.05
English learner	0.20	0.14
Receives special education services	0.36	0.11
Pretest is algebra I	1.10	0.14
Pretest is geometry	1.92	0.17
Pretest year is 2013	0.25	0.09
Pretest year is 2014	0.94	0.20
Pretest year is 2015	0.26	1.58
District percent rural	-0.21	0.12
Imputed for baseline score	0.05	0.15
Constant	-0.76	0.16
Number of enrollments		
Virtual Virginia	296	
Face to face	29,846	
Total	30,142	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B23. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes – English language arts

	Estimate	SE
Virtual Virginia course	-0.02	0.16
Baseline score	0.99	0.02
Grade 10	-0.41	1.29
Grade 11	0.22	1.36
Grade 12	1.03	1.41
Outcome subject is English language	0.58	0.26
Outcome year is 2016/17	-0.16	0.06
Student age	-0.27	0.04
Male	-0.07	0.03
Black/African American	-0.74	0.07
Hispanic	-0.19	0.06
Asian	0.37	0.08
Economically disadvantaged	-0.71	0.06
Gifted	0.85	0.04
English learner	-0.54	0.13
Receives special education services	-0.15	0.08
Pretest year is 2013	0.26	0.07
Pretest year is 2014	-0.27	0.54
Pretest year is 2015	-0.78	1.02
District percent rural	-0.36	0.11
Imputed for baseline score	0.55	0.05
Constant	0.37	0.13
Number of enrollments		
Virtual Virginia	291	
Face to face	41,835	
Total	42,126	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B24. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes – Science

	Estimate	SE
Virtual Virginia course	-0.67	0.17
Baseline score	1.13	0.03
Grade 10	0.98	0.25
Grade 11	1.20	0.34
Grade 12	1.50	0.37
Outcome test is biology	2.19	0.13
Outcome test is environmental science	1.34	0.15
Outcome year is 2016/17	0.37	0.07
Student age	-0.28	0.04
Male	0.45	0.04
Black/African American	-1.13	0.08
Hispanic	-0.44	0.08
Asian	-0.08	0.05
Economically disadvantaged	-0.59	0.07
Gifted	0.64	0.05
English learner	0.25	0.16
Receives special education services	<0.01	0.08
Pretest year is 2013	-0.05	0.08
Pretest year is 2014	0.12	0.18
Pretest year is 2015	0.20	0.28
District percent rural	-0.41	0.12
Imputed for baseline score	0.17	0.08
Constant	-1.02	0.11
Number of enrollments		
Virtual Virginia	456	
Face to face	28,022	
Total	28,478	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B25. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes – History and social science

	Estimate	SE
Virtual Virginia course	-0.76	0.10
Baseline score	0.94	0.02
Grade 10	0.68	0.22
Grade 11	1.08	0.25
Grade 12	1.07	0.26
Outcome test is art history	-0.04	0.26
Outcome test is European history	-0.90	0.14
Outcome test is comparative government	-0.66	0.17
Outcome test is U.S. government	-0.37	0.13
Outcome test is human geography	-0.09	0.12
Outcome test is macroeconomics	-0.48	0.22
Outcome test is microeconomics	-0.18	0.20
Outcome test is psychology	0.25	0.13
Outcome test is U.S. history	-0.61	0.14
Outcome year is 2016/17	0.11	0.04
Student age	-0.22	0.02
Male	0.33	0.03
Black/African American	-0.69	0.06
Hispanic	-0.31	0.05
Asian	0.26	0.06
Economically disadvantaged	-0.56	0.05
Gifted	0.70	0.03
English learner	-0.04	0.08
Receives special education services	-0.03	0.05
Pretest year is 2013	-0.20	0.05
Pretest year is 2014	-0.11	0.10
Pretest year is 2015	-0.25	0.20
District percent rural	-0.24	0.11
Imputed for baseline score	0.38	0.04
Constant	0.93	0.09
Number of enrollments		
Virtual Virginia	2,143	
Face to face	106,974	
Total	109,117	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit B26. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes – Languages

	Estimate	SE
Virtual Virginia course	-0.47	0.40
Baseline score	0.65	0.08
Grade 11	0.06	0.99
Grade 12	0.54	0.54
Outcome test is Chinese	-0.35	0.59
Outcome test is French	-1.26	0.24
Outcome test is Latin	-2.11	0.28
Outcome year is 2016/17	-0.89	0.65
Student age	-0.37	0.14
Male	-0.21	0.11
Black/African American	-0.87	0.22
Hispanic	1.17	0.23
Asian	0.41	0.22
Economically disadvantaged	-0.18	0.18
Gifted	0.23	0.15
English learner	1.35	0.39
Receives special education services	-0.46	0.25
Pretest year is 2013	0.39	0.78
Pretest year is 2014	-12.20	1.32
District percent rural	-0.34	0.25
Imputed for baseline score	0.58	0.23
Constant	3.35	0.26
Number of enrollments		
Virtual Virginia	136	
Face to face	3,417	
Total	3,553	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Appendix C: Sensitivity analyses

To test the sensitivity of the estimates shown in appendix B to certain model specifications, the study team ran the same models using four alternative specifications: using a student's mean score within subject area as the outcome, adding division fixed effects, using alternative versions of the demographic variables used as controls, and adding interactions between student grade level and the outcome course.

A summary of the results from these sensitivity tests is shown in exhibit C1. Detailed results and explanations of the tests are shown in the subsequent sections.

Exhibit C1. Summary of sensitivity tests on the relationship between Virtual Virginia and test outcomes

	SOL exam scores	SOL proficiency	AP exam scores	AP proficiency
Mathematics				
Main specification	-0.40	-1.42	-0.34	-0.81
Mean score outcome	-0.44	-1.61	-0.31	-0.48
Division fixed effects	-0.39	-1.42	-0.26	-0.68
Alternate versions of demographic variables	-0.39	-1.40	-0.33	-0.76
Interaction between grade level and baseline course	-0.46	-1.47	-0.34	-0.80
English language arts				
Main specification	-0.05	-0.21	-0.06	-0.02
Mean score outcome	-0.05	-0.21	-0.06	-0.03
Division fixed effects	-0.05	-0.27	0.02	0.19
Alternate versions of demographic variables	-0.04	-0.24	-0.01	0.10
Interaction between grade level and baseline course	N/A	N/A	-0.06	-0.01
Science				
Main specification	-0.32	-1.08	-0.24	-0.67
Mean score outcome	-0.25	-1.04	-0.27	-0.82
Division fixed effects	-0.30	-1.05	-0.22	-0.68
Alternate versions of demographic variables	-0.31	-1.06	-0.22	-0.62
Interaction between grade level and baseline course	-0.34	-1.17	-0.27	-0.70
History and social science				
Main specification	N/A	N/A	-0.31	-0.76
Mean score outcome	N/A	N/A	-0.31	-0.75
Division fixed effects	N/A	N/A	-0.08	-0.24
Alternate versions of demographic variables	N/A	N/A	-0.28	-0.67
Interaction between grade level and baseline course	N/A	N/A	-0.34	-0.82
Languages				
Main specification	N/A	N/A	-0.19	-0.47
Mean score outcome	N/A	N/A	-0.29	-0.58
Division fixed effects	N/A	N/A	-0.02	-0.33
Alternate versions of demographic variables	N/A	N/A	-0.24	-0.51
Interaction between grade level and baseline course	N/A	N/A	-0.19	-0.49

N/A is not applicable.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Mean score within subject area

In the main analysis, test scores were each treated independently, even when students took more than one test in the same subject area in the same year. That is, students who took both the AP U.S. history and the AP world history exam in the same year had two records contributing to the estimates of the relationship between VVA

and AP exam scores in history and social science. This sensitivity analysis examined an alternative approach in which we used mean test scores within each subject area. In the example above, the student's two AP exam scores were averaged, and she appeared only once in this analysis. No substantive differences were found in the estimates of the relationship between VVA and test score outcomes.

Standards of Learning outcomes

Results of the sensitivity analyses for courses with SOL exams follow.

Standards of Learning exam scores

The results for the sensitivity analyses based on the *z*-score translation of continuous SOL exam scores are in exhibits C2 to C4.

Exhibit C2. Full model results for the relationship between Virtual Virginia and mean Standards of Learning score outcomes within area – Mathematics

	Estimate	SE
Virtual Virginia course	-0.44	0.04
Mean baseline score	0.45	0.01
Grade 9	0.06	0.02
Grade 10	0.13	0.04
Grade 11	0.09	0.05
Grade 12	0.21	0.07
Outcome year is 2016/17	-0.12	0.02
Student age	-0.10	<0.01
Male	-0.02	<0.01
Black/African American	-0.16	0.01
Hispanic	-0.06	0.01
Asian	0.24	0.01
Economically disadvantaged	-0.17	0.01
Gifted	0.43	0.01
English learner	-0.03	0.01
Receives special education services	-0.19	0.01
Pretest year is 2012	0.20	0.02
Pretest year is 2013	0.44	0.04
Pretest year is 2014	0.70	0.05
Pretest year is 2015	0.88	0.07
District percent rural	-0.09	0.02
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.10	0.20
Imputed for English learner status	-1.00	0.21
Imputed for baseline score	-0.04	0.01
Constant	-0.13	0.01
Number of students		
Virtual Virginia	1,681	
Face to face	377,050	
Total	378,731	

Note: This analysis uses *z*-scores as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores are created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student is below the average for his or her grade level and school year, while a positive number indicates that a student is above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C3. Full model results for the relationship between Virtual Virginia and mean Standards of Learning score outcomes within area – English language arts

	Estimate	SE
Virtual Virginia course	-0.05	0.03
Baseline score	0.58	<0.01
Grade 10	0.22	0.07
Grade 11	0.45	0.07
Grade 12	0.39	0.07
Outcome year is 2016/17	0.02	0.02
Student age	-0.16	0.01
Male	-0.01	<0.01
Black/African American	-0.19	0.01
Hispanic	-0.03	0.01
Asian	0.01	0.01
Economically disadvantaged	-0.14	0.01
Gifted	0.27	0.01
English learner	-0.24	0.02
Receives special education services	-0.23	0.01
Pretest year is 2012	0.08	0.03
Pretest year is 2013	0.08	0.04
Pretest year is 2014	0.10	0.06
Pretest year is 2015	0.55	0.14
District percent rural	-0.06	0.02
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.01	0.25
Imputed for English learner status	-0.77	0.27
Imputed for baseline score	-0.07	0.01
Constant	0.04	0.04
Number of students		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: This analysis uses *z*-scores as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores are created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student is below the average for his or her grade level and school year, while a positive number indicates that a student is above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C4. Full model results for the relationship between Virtual Virginia and mean Standards of Learning score outcomes within area – Science

	Estimate	SE
Virtual Virginia course	-0.25	0.03
Baseline score	0.59	0.01
Grade 10	0.06	0.01
Grade 11	<0.01	0.03
Grade 12	0.15	0.04
Outcome year is 2016/17	-0.08	0.01
Student age	-0.11	<0.01
Male	<0.01	<0.01
Black/African American	-0.18	0.01
Hispanic	-0.08	0.01
Asian	0.09	0.01
Economically disadvantaged	-0.11	0.01
Gifted	0.27	0.01
English learner	-0.11	0.01
Receives special education services	-0.18	0.01
Pretest year is 2012	0.21	0.02
Pretest year is 2013	0.36	0.03
Pretest year is 2014	0.50	0.04
Pretest year is 2015	0.60	0.05
District percent rural	-0.04	0.01
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.20	0.42
Imputed for English learner status	-0.45	0.42
Imputed for baseline score	-0.03	0.01
Constant	-0.06	0.01
Number of students		
Virtual Virginia	1,757	
Face to face	410,833	
Total	412,590	

Note: This analysis uses *z*-scores as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores are created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student is below the average for his or her grade level and school year, while a positive number indicates that a student is above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Standards of Learning proficiency

The results for the sensitivity analyses based on the dichotomization of SOL exam scores are in exhibits C5 to C8.

Exhibit C5. Full model results for the relationship between Virtual Virginia and mean Standards of Learning proficiency outcomes – Mathematics

	Estimate	SE
Virtual Virginia course	-1.61	0.13
Baseline score	1.66	0.02
Grade 9	-0.10	0.07
Grade 10	0.47	0.08
Grade 11	1.11	0.12
Grade 12	1.70	0.16
Outcome year is 2016/17	-0.48	0.05
Student age	-0.35	0.01
Male	-0.10	0.01
Black/African American	-0.54	0.04
Hispanic	-0.19	0.04
Asian	0.53	0.04
Economically disadvantaged	-0.51	0.02
Gifted	1.28	0.04
English learner	-0.18	0.03
Receives special education services	-0.70	0.03
Pretest year is 2012	0.46	0.06
Pretest year is 2013	0.99	0.10
Pretest year is 2014	1.45	0.13
Pretest year is 2015	1.98	0.17
District percent rural	-0.25	0.06
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.22	0.62
Imputed for English learner status	-1.68	0.68
Imputed for baseline score	-0.22	0.02
Constant	-0.11	0.03
Number of enrollments		
Virtual Virginia	1,681	
Face to face	377,050	
Total	378,731	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0-399 means a student did not pass the test. A score of 400-499 means a student passed a test and was classified as proficient, and a score of 500-600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C6. Full model results for the relationship between Virtual Virginia and mean Standards of Learning proficiency outcomes – English language arts

	Estimate	SE
Virtual Virginia course	-0.21	0.12
Baseline score	2.21	0.02
Grade 10	0.77	0.18
Grade 11	1.62	0.19
Grade 12	1.64	0.22
Outcome year is 2016/17	-0.10	0.06
Student age	-0.52	0.02
Male	-0.02	0.02
Black/African American	-0.62	0.04
Hispanic	0.04	0.04
Asian	0.22	0.06
Economically disadvantaged	-0.52	0.02
Gifted	1.38	0.14
English learner	-0.87	0.05
Receives special education services	-1.04	0.03
Pretest year is 2012	-0.20	0.09
Pretest year is 2013	-0.18	0.13
Pretest year is 2014	-0.27	0.19
Pretest year is 2015	0.98	0.53
District percent rural	-0.19	0.05
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.10	0.76
Imputed for English learner status	-1.15	0.82
Imputed for baseline score	-0.33	0.04
Constant	0.55	0.15
Number of enrollments		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0-399 means a student did not pass the test. A score of 400-499 means a student passed a test and was classified as proficient, and a score of 500-600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C7. Full model results for the relationship between Virtual Virginia and mean Standards of Learning proficiency outcomes – Science

	Estimate	SE
Virtual Virginia course	-1.04	0.09
Baseline score	2.19	0.02
Grade 10	0.80	0.04
Grade 11	1.26	0.09
Grade 12	1.89	0.13
Outcome year is 2016/17	-0.32	0.04
Student age	-0.48	0.01
Male	0.04	0.01
Black/African American	-0.68	0.03
Hispanic	-0.26	0.03
Asian	0.42	0.04
Economically disadvantaged	-0.51	0.02
Gifted	1.56	0.08
English learner	-0.57	0.04
Receives special education services	-0.90	0.02
Pretest year is 2012	0.24	0.08
Pretest year is 2013	0.69	0.11
Pretest year is 2014	1.13	0.13
Pretest year is 2015	1.43	0.16
District percent rural	-0.04	0.04
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.50	0.58
Imputed for English learner status	-0.80	0.58
Imputed for baseline score	-0.05	0.04
Constant	0.14	0.03
Number of enrollments		
Virtual Virginia	1,757	
Face to face	410,833	
Total	412,590	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0-399 means a student did not pass the test. A score of 400-499 means a student passed a test and was classified as proficient, and a score of 500-600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement outcomes

Results of the sensitivity analyses using the mean AP exam score at the student level follow.

Advanced Placement test scores

The results for the sensitivity analyses based on the *z*-score translation of AP exam scores at the student level are in exhibits C8 to C12.

Exhibit C8. Full model results for the relationship between Virtual Virginia and mean Advanced Placement score outcomes – Mathematics

	Estimate	SE
Virtual Virginia course	-0.31	0.07
Baseline score	0.36	0.01
Grade 10	-0.05	0.10
Grade 11	-0.09	0.12
Grade 12	-0.14	0.14
Outcome year is 2016/17	0.01	0.02
Student age	-0.14	0.02
Male	0.09	0.01
Black/African American	-0.32	0.03
Hispanic	-0.19	0.03
Asian	0.03	0.03
Economically disadvantaged	-0.23	0.03
Gifted	0.31	0.02
English learner	-0.05	0.05
Receives special education services	0.05	0.03
Pretest year is 2013	0.04	0.04
Pretest year is 2014	0.15	0.07
Pretest year is 2015	0.05	0.17
District percent rural	-0.12	0.06
Imputed for baseline score	0.17	0.05
Constant	-0.01	0.04
Number of students		
Virtual Virginia	273	
Face to face	28,684	
Total	28,957	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C9. Full model results for the relationship between Virtual Virginia and mean Advanced Placement score outcomes – English language arts

	Estimate	SE
Virtual Virginia course	-0.06	0.06
Baseline score	0.40	0.01
Grade 10	<0.01	<0.01
Grade 11	0.20	0.23
Grade 12	0.36	0.24
Outcome year is 2016/17	-0.05	0.03
Student age	-0.12	0.02
Male	-0.05	0.02
Black/African American	-0.32	0.03
Hispanic	-0.11	0.02
Asian	0.16	0.04
Economically disadvantaged	-0.29	0.02
Gifted	0.41	0.02
English learner	-0.02	0.04
Receives special education services	-0.04	0.03
Pretest year is 2013	0.07	0.03
Pretest year is 2014	0.09	0.36
Pretest year is 2015	<0.01	<0.01
District percent rural	-0.20	0.06
Imputed for baseline score	-0.10	0.10
Constant	-0.08	0.04
Number of enrollments		
Virtual Virginia	257	
Face to face	37,122	
Total	37,379	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C10. Full model results for the relationship between Virtual Virginia and mean Advanced Placement score outcomes – Science

	Estimate	SE
Virtual Virginia course	-0.27	0.06
Baseline score	0.49	0.01
Grade 10	0.44	0.15
Grade 11	0.46	0.13
Grade 12	0.69	0.14
Outcome year is 2016/17	0.03	0.03
Student age	-0.11	0.02
Male	0.11	0.02
Black/African American	-0.39	0.03
Hispanic	-0.21	0.03
Asian	-0.06	0.04
Economically disadvantaged	-0.19	0.02
Gifted	0.26	0.02
English learner	0.10	0.05
Receives special education services	0.05	0.03
Pretest year is 2013	0.10	0.04
Pretest year is 2014	0.19	0.08
Pretest year is 2015	0.22	0.11
District percent rural	-0.17	0.06
Imputed for baseline score	0.01	0.13
Constant	-0.02	0.04
Number of students		
Virtual Virginia	328	
Face to face	20,534	
Total	20,862	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C11. Full model output for the relationship between Virtual Virginia and mean Advanced Placement score outcomes – History and social science

	Estimate	SE
Virtual Virginia course	-0.31	0.04
Baseline score	0.39	0.01
Grade 10	0.21	0.08
Grade 11	0.31	0.10
Grade 12	0.39	0.11
Outcome year is 2016/17	0.02	0.02
Student age	-0.09	0.01
Male	0.11	0.01
Black/African American	-0.31	0.03
Hispanic	-0.12	0.02
Asian	0.14	0.02
Economically disadvantaged	-0.27	0.02
Gifted	0.34	0.01
English learner	0.02	0.03
Receives special education services	0.01	0.02
Pretest year is 2013	-0.02	0.02
Pretest year is 2014	-0.02	0.05
Pretest year is 2015	-0.04	0.08
District percent rural	-0.12	0.05
Imputed for baseline score	0.03	0.08
Constant	-0.03	0.03
Number of students		
Virtual Virginia	1,360	
Face to face	83,327	
Total	84,687	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C12. Full model output for the relationship between Virtual Virginia and mean Advanced Placement score outcomes – Languages

	Estimate	SE
Virtual Virginia course	-0.29	0.20
Baseline score	0.26	0.02
Grade 10	-0.85	0.48
Grade 11	-0.55	0.37
Grade 12	-0.16	0.28
Outcome year is 2016/17	-0.49	0.24
Student age	-0.16	0.05
Male	-0.05	0.04
Black/African American	-0.34	0.09
Hispanic	0.62	0.07
Asian	0.07	0.10
Economically disadvantaged	-0.03	0.06
Gifted	0.16	0.04
English learner	0.31	0.09
Receives special education services	-0.23	0.09
Pretest year is 2013	0.44	0.26
Pretest year is 2014	0.93	0.45
District percent rural	-0.20	0.11
Imputed for baseline score	0.41	0.31
Constant	<0.01	0.12
Number of students		
Virtual Virginia	118	
Face to face	2,982	
Total	3,100	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement proficiency

The results for the sensitivity analyses based on the dichotomization of AP exam scores are in exhibits C13 to C17.

Exhibit C13. Full model output for the relationship between Virtual Virginia and mean Advanced Placement proficiency outcomes – Mathematics

	Estimate	SE
Virtual Virginia course	-0.48	0.17
Baseline score	0.82	0.04
Grade 10	-1.14	1.02
Grade 11	-1.18	1.15
Grade 12	-1.33	1.20
Outcome year is 2016/17	-0.14	0.05
Student age	-0.30	0.05
Male	0.25	0.03
Black/African American	-0.75	0.09
Hispanic	-0.39	0.07
Asian	0.09	0.08
Economically disadvantaged	-0.58	0.07
Gifted	0.69	0.04
English learner	-0.11	0.14
Receives special education services	0.24	0.10
Pretest year is 2013	0.15	0.09
Pretest year is 2014	0.71	0.20
Pretest year is 2015	-0.31	1.46
District percent rural	-0.08	0.13
Imputed for baseline score	0.39	0.14
Constant	0.59	0.09
Number of enrollments		
Virtual Virginia	273	
Face to face	28,684	
Total	28,957	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C14. Full model output for the relationship between Virtual Virginia and mean Advanced Placement proficiency outcomes – English language arts

	Estimate	SE
Virtual Virginia course	-0.03	0.17
Baseline score	1.01	0.02
Grade 10	-0.92	0.60
Grade 11	-0.28	0.08
Outcome year is 2016/17	-0.20	0.07
Student age	-0.30	0.04
Male	-0.09	0.04
Black/African American	-0.69	0.07
Hispanic	-0.21	0.06
Asian	0.39	0.09
Economically disadvantaged	-0.71	0.06
Gifted	0.87	0.04
English learner	-0.36	0.12
Receives special education services	-0.16	0.09
Pretest year is 2013	0.28	0.08
Pretest year is 2014	-0.48	0.81
District percent rural	-0.37	0.12
Imputed for baseline score	-0.22	0.29
Constant	0.49	0.09
Number of enrollments		
Virtual Virginia	257	
Face to face	37,122	
Total	37,379	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C15. Full model output for the relationship between Virtual Virginia and mean Advanced Placement proficiency outcomes – Science

	Estimate	SE
Virtual Virginia course	-0.82	0.19
Baseline score	1.12	0.03
Grade 10	1.66	0.30
Grade 11	1.22	0.41
Grade 12	2.00	0.43
Outcome year is 2016/17	0.24	0.09
Student age	-0.24	0.05
Male	0.06	0.05
Black/African American	-0.95	0.10
Hispanic	-0.45	0.09
Asian	-0.08	0.07
Economically disadvantaged	-0.50	0.07
Gifted	0.42	0.06
English learner	0.06	0.17
Receives special education services	0.04	0.09
Pretest year is 2013	0.21	0.11
Pretest year is 2014	0.48	0.21
Pretest year is 2015	0.55	0.35
District percent rural	-0.03	0.15
Imputed for baseline score	0.20	0.43
Constant	0.12	0.09
Number of enrollments		
Virtual Virginia	328	
Face to face	20,534	
Total	20,862	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C16. Full model output for the relationship between Virtual Virginia and mean Advanced Placement proficiency outcomes – History and social science

	Estimate	SE
Virtual Virginia course	-0.75	0.10
Baseline score	0.91	0.02
Grade 10	0.61	0.20
Grade 11	0.71	0.23
Grade 12	0.80	0.25
Outcome year is 2016/17	0.12	0.05
Student age	-0.21	0.02
Male	0.27	0.03
Black/African American	-0.67	0.07
Hispanic	-0.27	0.06
Asian	0.34	0.06
Economically disadvantaged	-0.57	0.05
Gifted	0.68	0.03
English learner	0.02	0.08
Receives special education services	0.03	0.05
Pretest year is 2013	-0.23	0.06
Pretest year is 2014	-0.18	0.12
Pretest year is 2015	-0.34	0.22
District percent rural	-0.18	0.12
Imputed for baseline score	-0.02	0.21
Constant	0.61	0.07
Number of enrollments		
Virtual Virginia	1,360	
Face to face	83,327	
Total	84,687	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C17. Full model output for the relationship between Virtual Virginia and mean Advanced Placement proficiency outcomes – Languages

	Estimate	SE
Virtual Virginia course	-0.58	0.41
Baseline score	0.51	0.08
Grade 10	13.51	1.43
Grade 11	0.85	1.10
Grade 12	1.11	0.74
Outcome year is 2016/17	-0.64	0.67
Student age	-0.28	0.15
Male	-0.23	0.13
Black/African American	-0.86	0.23
Hispanic	1.63	0.22
Asian	0.34	0.23
Economically disadvantaged	-0.06	0.18
Gifted	0.16	0.14
English learner	1.01	0.39
Receives special education services	-0.50	0.27
Pretest year is 2013	0.15	0.76
Pretest year is 2014	-11.61	1.28
District percent rural	-0.52	0.22
Imputed for baseline score	<0.01	<0.01
Constant	2.50	0.25
Number of enrollments		
Virtual Virginia	118	
Face to face	2,973	
Total	3,091	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Division fixed effects

The main models reported in appendix B were single-level models with standard errors clustered at the school level. This alternative analysis added district-level fixed effects to account for all time-invariant preexisting differences between districts. This alternative specification did not substantially change the estimates on SOL proficiency or scaled score outcomes. On the AP exam outcomes, the additional control for district fixed effects reduced the size of the estimates so that the relationship between VVA and AP exam scores in history and social science was no longer substantively important. The relationship between VVA and other AP exam outcomes did not substantially change. Thus, it appears that some portion of the relationship between VVA and AP exam outcomes in history and social science may be explained by preexisting differences between districts.

Standards of Learning outcomes

Results of the sensitivity analyses for courses with SOL exams follow.

Standards of Learning test scores

The results for the sensitivity analyses based on the *z*-score translation of continuous SOL exam scores are in exhibits C18 to C20.

Exhibit C18. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with district fixed effects – Mathematics

	Estimate	SE
Virtual Virginia course	-0.39	0.04
Baseline score	0.46	<0.01
Grade 9	-0.31	0.03
Grade 10	-0.39	0.04
Grade 11	-0.47	0.06
Grade 12	-0.48	0.08
Outcome test is algebra II	<0.01	0.02
Outcome test is geometry	0.14	0.02
Outcome year is 2016/17	0.04	0.02
Student age	-0.09	<0.01
Male	-0.02	<0.01
Black/African American	-0.12	0.01
Hispanic	-0.05	0.01
Asian	0.17	0.01
Economically disadvantaged	-0.11	<0.01
Gifted	0.26	0.01
English learner	-0.02	0.01
Receives special education services	-0.14	0.01
Pretest is geometry	0.35	0.02
Pretest is mathematics 6	-0.49	0.03
Pretest is mathematics 7	-0.42	0.01
Pretest year is 2012	0.07	0.02
Pretest year is 2013	0.17	0.04
Pretest year is 2014	0.28	0.05
Pretest year is 2015	0.29	0.07
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.07	0.10
Imputed for English learner status	-0.01	0.17
Imputed for baseline score	-0.70	0.39
Constant	-0.02	0.04
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C19. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with district fixed effects – English language arts

	Estimate	SE
Virtual Virginia course	-0.05	0.03
Baseline score	0.57	<0.01
Grade 10	0.27	0.05
Grade 11	0.49	0.05
Grade 12	0.46	0.05
Outcome year is 2016/17	<0.01	0.02
Student age	-0.16	0.01
Male	-0.01	<0.01
Black/African American	-0.19	0.01
Hispanic	-0.07	0.01
Asian	-0.06	0.01
Economically disadvantaged	-0.12	0.01
Gifted	0.27	0.01
English learner	-0.28	0.02
Receives special education services	-0.25	0.01
Pretest year is 2012	0.11	0.03
Pretest year is 2013	0.14	0.04
Pretest year is 2014	0.19	0.06
Pretest year is 2015	0.63	0.15
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.06	0.20
Imputed for English learner status	-0.86	0.20
Imputed for baseline score	-0.07	0.01
Constant	-0.02	0.04
Number of enrollments		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C20. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with district fixed effects – Science

	Estimate	SE
Virtual Virginia course	-0.30	0.03
Baseline score	0.61	0.01
Grade 10	0.18	0.01
Grade 11	0.20	0.03
Grade 12	0.28	0.04
Outcome test is chemistry	-0.22	0.01
Outcome test is earth science	0.20	0.01
Outcome year is 2016/17	-0.02	0.01
Student age	-0.13	<0.01
Male	-0.01	<0.01
Black/African American	-0.16	0.01
Hispanic	-0.07	0.01
Asian	0.13	0.01
Economically disadvantaged	-0.13	<0.01
Gifted	0.30	0.01
English learner	-0.13	0.01
Receives special education services	-0.20	0.01
Pretest year is 2012	0.19	0.02
Pretest year is 2013	0.28	0.03
Pretest year is 2014	0.35	0.04
Pretest year is 2015	0.40	0.05
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.21	0.38
Imputed for English learner status	-0.54	0.38
Imputed for baseline score	0.01	0.01
Constant	-0.03	0.04
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Standards of Learning proficiency

The results for the sensitivity analyses based on the dichotomization of SOL exam scores are in Exhibits C21 to C23.

Exhibit C21. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with district fixed effects – Mathematics

	Estimate	SE
Virtual Virginia course	-1.42	0.15
Baseline score	1.49	0.02
Grade 9	-0.85	0.08
Grade 10	-0.84	0.11
Grade 11	-0.68	0.14
Grade 12	-0.40	0.18
Outcome test is algebra II	0.90	0.06
Outcome test is geometry	0.24	0.05
Outcome year is 2016/17	-0.27	0.05
Student age	-0.32	0.01
Male	-0.09	0.01
Black/African American	-0.44	0.02
Hispanic	-0.19	0.03
Asian	0.40	0.04
Economically disadvantaged	-0.38	0.02
Gifted	0.92	0.03
English learner	-0.10	0.03
Receives special education services	-0.61	0.02
Pretest is algebra I	0.95	0.10
Pretest is geometry	1.09	0.13
Pretest is mathematics 8	0.41	0.09
Pretest year is 2012	0.25	0.06
Pretest year is 2013	0.58	0.10
Pretest year is 2014	0.82	0.13
Pretest year is 2015	1.09	0.17
District percent rural	0.16	0.14
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.48	0.56
Imputed for English learner status	-1.13	0.64
Imputed for baseline score	0.02	0.02
Constant	-0.56	0.09
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C22. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with district fixed effects – English language arts

	Estimate	SE
Virtual Virginia course	-0.27	0.11
Baseline score	2.18	0.02
Grade 10	0.92	0.16
Grade 11	1.82	0.16
Grade 12	1.86	0.18
Outcome year is 2016/17	-0.18	0.06
Student age	-0.50	0.02
Male	-0.02	0.02
Black/African American	-0.68	0.03
Hispanic	-0.15	0.04
Asian	-0.09	0.06
Economically disadvantaged	-0.47	0.02
Gifted	1.40	0.12
English learner	-1.06	0.05
Receives special education services	-1.15	0.03
Pretest year is 2012	-0.08	0.09
Pretest year is 2013	0.01	0.13
Pretest year is 2014	0.11	0.19
Pretest year is 2015	1.08	0.45
District percent rural	0.17	0.12
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.01	1.26
Imputed for English learner status	-1.04	1.26
Imputed for baseline score	-0.37	0.03
Constant	0.28	0.15
Number of enrollments		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C23. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with district fixed effects – Science

	Estimate	SE
Virtual Virginia course	-1.05	0.08
Baseline score	2.20	0.02
Grade 10	0.87	0.04
Grade 11	1.36	0.07
Grade 12	1.95	0.11
Outcome test is chemistry	-0.11	0.04
Outcome test is earth science	0.19	0.04
Outcome year is 2016/17	-0.27	0.03
Student age	-0.49	0.01
Male	0.04	0.01
Black/African American	-0.67	0.02
Hispanic	-0.32	0.03
Asian	0.34	0.03
Economically disadvantaged	-0.49	0.02
Gifted	1.57	0.08
English learner	-0.65	0.04
Receives special education services	-0.96	0.02
Pretest year is 2012	0.25	0.08
Pretest year is 2013	0.66	0.10
Pretest year is 2014	1.05	0.12
Pretest year is 2015	1.30	0.15
District percent rural	-0.04	0.18
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.79	0.53
Imputed for English learner status	-0.39	0.59
Imputed for baseline score	0.01	0.04
Constant	-0.12	0.10
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement outcomes

Results of the sensitivity analyses for courses with AP exams follow.

Advanced Placement test scores

The results for the sensitivity analyses based on the *z*-score translation of AP exam scores are in Exhibits C24 to C28.

Exhibit C24. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with district fixed effects – Mathematics

	Estimate	SE
Virtual Virginia course	-0.26	0.08
Baseline score	0.39	0.01
Grade 10	-0.01	0.10
Grade 11	-0.04	0.13
Grade 12	0.08	0.16
Outcome test is calculus AB	-0.15	0.05
Outcome test is calculus BC	-0.33	0.05
Outcome test is computer science	-0.40	0.07
Outcome year is 2016/17	-0.02	0.02
Student age	-0.15	0.02
Male	0.13	0.01
Black/African American	-0.24	0.03
Hispanic	-0.15	0.02
Asian	-0.06	0.02
Economically disadvantaged	-0.14	0.02
Gifted	0.20	0.01
English learner	0.08	0.05
Receives special education services	0.09	0.03
Pretest is algebra I	0.38	0.05
Pretest is geometry	0.79	0.05
Pretest year is 2013	0.10	0.03
Pretest year is 2014	0.33	0.07
Pretest year is 2015	0.42	0.18
District percent rural	0.19	0.11
Imputed for baseline score	-0.05	0.07
Constant	-0.64	0.07
Number of enrollments		
Virtual Virginia	296	
Face to face	29,846	
Total	30,142	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C25. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with district fixed effects – English language arts

	Estimate	SE
Virtual Virginia course	0.02	0.06
Baseline score	0.39	0.01
Grade 10	0.51	0.93
Grade 11	0.66	0.98
Grade 12	1.05	1.01
Outcome subject is English language	0.25	0.15
Outcome year is 2016/17	-0.03	0.02
Student age	-0.11	0.01
Male	-0.04	0.01
Black/African American	-0.31	0.03
Hispanic	-0.12	0.02
Asian	0.07	0.03
Economically disadvantaged	-0.25	0.02
Gifted	0.41	0.01
English learner	-0.09	0.05
Receives special education services	-0.05	0.03
Pretest year is 2013	0.05	0.03
Pretest year is 2014	0.05	0.24
Pretest year is 2015	0.05	0.83
District percent rural	-0.34	0.07
Imputed for baseline score	0.25	0.02
Constant	-0.13	0.07
Number of enrollments		
Virtual Virginia	291	
Face to face	41,835	
Total	42,126	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C26. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with district fixed effects – Science

	Estimate	SE
Virtual Virginia course	-0.22	0.09
Baseline score	0.46	0.01
Grade 10	0.37	0.09
Grade 11	0.32	0.09
Grade 12	0.45	0.11
Outcome test is biology	0.18	0.06
Outcome test is environmental science	0.31	0.06
Outcome year is 2016/17	0.07	0.03
Student age	-0.12	0.01
Male	0.18	0.02
Black/African American	-0.35	0.02
Hispanic	-0.17	0.02
Asian	-0.05	0.03
Economically disadvantaged	-0.16	0.02
Gifted	0.29	0.02
English learner	0.09	0.05
Receives special education services	<0.01	0.03
Pretest year is 2013	0.02	0.03
Pretest year is 2014	0.07	0.06
Pretest year is 2015	0.08	0.10
District percent rural	0.27	0.11
Imputed for baseline score	0.12	0.03
Constant	-0.30	0.07
Number of enrollments		
Virtual Virginia	437	
Face to face	27,859	
Total	28,296	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C27. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with district fixed effects – History and social science

	Estimate	SE
Virtual Virginia course	-0.08	0.05
Baseline score	0.38	0.01
Grade 10	0.19	0.06
Grade 11	0.30	0.07
Grade 12	0.40	0.08
Outcome test is art history	-0.14	0.09
Outcome test is European history	-0.01	0.04
Outcome test is comparative government	0.06	0.06
Outcome test is U.S. government	-0.07	0.04
Outcome test is human geography	0.13	0.04
Outcome test is macroeconomics	-0.39	0.09
Outcome test is microeconomics	-0.29	0.07
Outcome test is psychology	0.08	0.04
Outcome test is U.S. history	<0.01	0.05
Outcome year is 2016/17	0.03	0.02
Student age	-0.10	0.01
Male	0.13	0.01
Black/African American	-0.24	0.02
Hispanic	-0.13	0.01
Asian	0.05	0.02
Economically disadvantaged	-0.18	0.01
Gifted	0.36	0.01
English learner	-0.08	0.03
Receives special education services	-0.06	0.02
Pretest year is 2013	-0.03	0.02
Pretest year is 2014	-0.02	0.04
Pretest year is 2015	-0.03	0.07
District percent rural	0.46	0.29
Imputed for baseline score	0.19	0.01
Constant	-0.08	0.13
Number of enrollments		
Virtual Virginia	2,143	
Face to face	106,974	
Total	109,117	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C28. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with district fixed effects – Languages

	Estimate	SE
Virtual Virginia course	-0.02	0.19
Baseline score	0.27	0.02
Grade 11	-0.20	0.19
Grade 12	-0.25	0.17
Outcome test is Chinese	-0.24	0.18
Outcome test is French	0.07	0.09
Outcome test is Latin	-0.03	0.13
Outcome year is 2016/17	-0.11	0.18
Student age	-0.17	0.04
Male	-0.02	0.03
Black/African American	-0.26	0.08
Hispanic	0.57	0.06
Asian	0.05	0.09
Economically disadvantaged	-0.01	0.07
Gifted	0.19	0.04
English learner	0.36	0.07
Receives special education services	-0.30	0.08
Pretest year is 2013	0.06	0.15
Pretest year is 2014	0.05	0.17
District percent rural	-0.29	0.22
Imputed for baseline score	0.34	0.05
Constant	-0.19	0.14
Number of enrollments		
Virtual Virginia	136	
Face to face	3,417	
Total	3,553	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement proficiency

The results for the sensitivity analyses based on the dichotomization of AP exam scores are in exhibits C29 to C33.

Exhibit C29. Full model results for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with district fixed effects – Mathematics

	Estimate	SE
Virtual Virginia course	-0.68	0.20
Baseline score	0.88	0.03
Grade 10	-0.46	1.01
Grade 11	-0.48	1.12
Grade 12	-0.15	1.17
Outcome test is calculus AB	0.11	0.11
Outcome test is calculus BC	0.63	0.12
Outcome test is computer science	-0.09	0.17
Outcome year is 2016/17	-0.20	0.05
Student age	-0.33	0.05
Male	0.28	0.03
Black/African American	-0.59	0.08
Hispanic	-0.34	0.06
Asian	-0.13	0.06
Economically disadvantaged	-0.37	0.06
Gifted	0.47	0.03
English learner	0.19	0.14
Receives special education services	0.31	0.10
Pretest is algebra I	1.06	0.15
Pretest is geometry	1.92	0.15
Pretest year is 2013	0.30	0.09
Pretest year is 2014	1.03	0.21
Pretest year is 2015	0.58	1.55
District percent rural	0.62	0.28
Imputed for baseline score	-0.05	0.18
Constant	-1.31	0.18
Number of enrollments		
Virtual Virginia	294	
Face to face	29,819	
Total	30,113	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C30. Full model results for the relationship between Virtual Virginia and Advanced Placement Proficiency outcome with district fixed effects – English language arts

	Estimate	SE
Virtual Virginia course	0.19	0.15
Baseline score	0.99	0.02
Grade 10	-0.62	2.64
Grade 11	-0.11	2.73
Grade 12	0.53	2.78
Outcome subject is English language	0.36	0.29
Outcome year is 2016/17	-0.14	0.06
Student age	-0.28	0.04
Male	-0.06	0.03
Black/African American	-0.69	0.07
Hispanic	-0.22	0.05
Asian	0.21	0.07
Economically disadvantaged	-0.62	0.06
Gifted	0.90	0.04
English learner	-0.49	0.13
Receives special education services	-0.18	0.09
Pretest year is 2013	0.25	0.08
Pretest year is 2014	-0.35	0.56
Pretest year is 2015	-1.21	2.31
District percent rural	-0.70	0.14
Imputed for baseline score	0.55	0.05
Constant	0.48	0.15
Number of enrollments		
Virtual Virginia	291	
Face to face	41,835	
Total	42,126	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C31. Full model results for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with district fixed effects – Science

	Estimate	SE
Virtual Virginia course	-0.68	0.20
Baseline score	1.16	0.03
Grade 10	0.80	0.20
Grade 11	0.89	0.27
Grade 12	1.18	0.30
Outcome test is biology	2.21	0.13
Outcome test is environmental science	1.40	0.15
Outcome year is 2016/17	0.44	0.07
Student age	-0.30	0.04
Male	0.48	0.05
Black/African American	-1.05	0.07
Hispanic	-0.42	0.07
Asian	-0.15	0.05
Economically disadvantaged	-0.48	0.06
Gifted	0.70	0.04
English learner	0.18	0.15
Receives special education services	-0.05	0.08
Pretest year is 2013	-0.05	0.08
Pretest year is 2014	0.08	0.19
Pretest year is 2015	0.11	0.31
District percent rural	0.69	0.28
Imputed for baseline score	0.36	0.07
Constant	-1.41	0.18
Number of enrollments		
Virtual Virginia	455	
Face to face	28,013	
Total	28,468	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C32. Full model results for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with district fixed effects – History and social science

	Estimate	SE
Virtual Virginia course	-0.24	0.11
Baseline score	0.94	0.02
Grade 10	0.44	0.14
Grade 11	0.70	0.18
Grade 12	0.81	0.20
Outcome test is art history	-0.26	0.25
Outcome test is European history	-0.95	0.10
Outcome test is comparative government	-0.62	0.14
Outcome test is U.S. government	-0.41	0.10
Outcome test is human geography	-0.12	0.09
Outcome test is macroeconomics	-0.64	0.20
Outcome test is microeconomics	-0.37	0.17
Outcome test is psychology	0.27	0.10
Outcome test is U.S. history	-0.49	0.11
Outcome year is 2016/17	0.16	0.04
Student age	-0.23	0.02
Male	0.35	0.03
Black/African American	-0.56	0.04
Hispanic	-0.32	0.03
Asian	0.07	0.05
Economically disadvantaged	-0.37	0.03
Gifted	0.79	0.03
English learner	-0.13	0.07
Receives special education services	-0.13	0.05
Pretest year is 2013	-0.23	0.05
Pretest year is 2014	-0.13	0.10
Pretest year is 2015	-0.27	0.18
District percent rural	1.15	0.60
Imputed for baseline score	0.40	0.04
Constant	0.69	0.27
Number of enrollments		
Virtual Virginia	2,143	
Face to face	106,974	
Total	109,117	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C33. Full model results for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with district fixed effects – Languages

	Estimate	SE
Virtual Virginia course	-0.33	0.48
Baseline score	0.67	0.08
Grade 10	13.04	1.48
Grade 11	-0.26	0.98
Grade 12	0.27	0.52
Outcome test is Chinese	-0.28	0.59
Outcome test is French	-1.22	0.23
Outcome test is Latin	-2.24	0.29
Outcome year is 2016/17	-0.90	0.68
Student age	-0.39	0.14
Male	-0.20	0.10
Black/African American	-0.85	0.21
Hispanic	1.20	0.22
Asian	0.30	0.21
Economically disadvantaged	-0.09	0.19
Gifted	0.42	0.16
English learner	1.44	0.39
Receives special education services	-0.52	0.25
Pretest year is 2013	0.65	0.81
Pretest year is 2014	-11.71	1.45
District percent rural	-0.68	0.72
Imputed for baseline score	0.63	0.23
Constant	3.30	0.44
Number of enrollments		
Virtual Virginia	135	
Face to face	3,404	
Total	3,539	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Alternative specifications of the demographic variables

As discussed in the "Data intake and cleaning" section of appendix A, the raw data the Virginia Department of Education supplied included duplicate records for students, with variation in the baseline achievement and demographic variables. This section presents results of alternative approaches to eliminating those duplicates.

In the models presented in appendix B, the study team used "ever" black, Hispanic, economically disadvantaged, gifted, English learner, received special education services, and male; that is, we created a variable that reflected if students ever appeared with a "yes" for the variable. In this sensitivity analysis, we use the inverse of this variable (that is, if a student was ever recorded as not economically disadvantaged in any record in the year, he or she was recorded as not economically disadvantaged for the entire year). For age, average age was used in the main analysis, whereas in this sensitivity analysis youngest age was used. Finally, for student race, division, school, and grade level, the study team selected the earliest instance in the school year for the main analysis and used the second instance for this analysis.

These alternative specifications of the control variables did not substantially change the results.

Standards of Learning outcomes

Results of the sensitivity analyses for courses with SOL exams follow.

Standards of Learning test scores

The results for the sensitivity analyses based on the *z*-score translation of continuous SOL exam scores are in exhibits C34 to C36.

Exhibit C34. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with alternate control variable specifications – Mathematics

	Estimate	SE
Virtual Virginia course	-0.39	0.04
Baseline score	0.49	0.01
Grade 9	-0.38	0.03
Grade 10	-0.46	0.04
Grade 11	-0.54	0.06
Grade 12	-0.55	0.07
Outcome test is algebra II	0.02	0.02
Outcome test is geometry	0.14	0.02
Outcome year is 2016/17	0.04	0.02
Student age	-0.10	<0.01
Male	-0.02	<0.01
Black/African American	-0.16	0.01
Hispanic	-0.06	0.01
Asian	0.19	0.01
Economically disadvantaged	-0.11	0.01
Gifted	0.17	0.27
English learner	-0.02	0.01
Receives special education services	-0.12	0.01
Pretest is algebra I	0.59	0.03
Pretest is geometry	0.98	0.04
Pretest is mathematics 8	0.14	0.03
Pretest year is 2012	0.08	0.02
Pretest year is 2013	0.19	0.04
Pretest year is 2014	0.30	0.05
Pretest year is 2015	0.31	0.07
District percent rural	-0.10	0.02
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.03	0.19
Imputed for English learner status	-0.89	0.20
Imputed for baseline score	0.11	0.01
Constant	-0.31	0.02
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C35. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with alternate control variable specifications – English language arts

	Estimate	SE
Virtual Virginia course	-0.04	0.03
Baseline score	0.61	<0.01
Grade 10	0.23	0.07
Grade 11	0.44	0.07
Grade 12	0.38	0.08
Outcome year is 2016/17	0.02	0.02
Student age	-0.16	0.01
Male	<0.01	<0.01
Black/African American	-0.20	0.01
Hispanic	-0.05	0.01
Asian	0.02	0.02
Economically disadvantaged	-0.13	0.01
Gifted	0.56	0.24
English learner	-0.24	0.02
Receives special education services	-0.23	0.01
Pretest year is 2012	0.08	0.03
Pretest year is 2013	0.08	0.04
Pretest year is 2014	0.09	0.06
Pretest year is 2015	0.51	0.16
District percent rural	-0.06	0.02
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.07	0.22
Imputed for English learner status	-0.82	0.24
Imputed for baseline score	-0.09	0.01
Constant	0.03	0.04
Number of enrollments		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C36. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with alternate control variable specifications – Science

	Estimate	SE
Virtual Virginia course	-0.31	0.03
Baseline score	0.65	0.01
Grade 10	0.17	0.01
Grade 11	0.17	0.03
Grade 12	0.26	0.04
Outcome test is chemistry	-0.18	0.01
Outcome test is earth science	0.17	0.01
Outcome year is 2016/17	-0.04	0.01
Student age	-0.13	<0.01
Male	-0.02	<0.01
Black/African American	-0.19	0.01
Hispanic	-0.08	0.01
Asian	0.15	0.01
Economically disadvantaged	-0.12	0.01
Gifted	0.41	0.27
English learner	-0.12	0.01
Receives special education services	-0.19	0.01
Pretest year is 2012	0.19	0.02
Pretest year is 2013	0.30	0.03
Pretest year is 2014	0.39	0.04
Pretest year is 2015	0.45	0.05
District percent rural	-0.07	0.01
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.21	0.40
Imputed for English learner status	-0.49	0.40
Imputed for baseline score	-0.01	0.02
Constant	-0.05	0.01
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Standards of Learning proficiency

The results for the sensitivity analyses based on the dichotomization of SOL exam scores are in exhibits C37 to C39.

Exhibit C37. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with alternate control variable specifications – Mathematics

	Estimate	SE
Virtual Virginia course	-1.40	0.15
Baseline score	1.56	0.02
Grade 9	-0.91	0.10
Grade 10	-0.89	0.12
Grade 11	-0.74	0.15
Grade 12	-0.43	0.19
Outcome test is algebra II	0.98	0.06
Outcome test is geometry	0.28	0.05
Outcome year is 2016/17	-0.26	0.05
Student age	-0.34	0.02
Male	-0.09	0.01
Black/African American	-0.57	0.04
Hispanic	-0.22	0.04
Asian	0.45	0.04
Economically disadvantaged	-0.37	0.02
Gifted	0.73	0.89
English learner	-0.15	0.04
Receives special education services	-0.58	0.03
Pretest is algebra I	1.07	0.11
Pretest is geometry	1.36	0.15
Pretest is mathematics 8	0.57	0.10
Pretest year is 2012	0.25	0.06
Pretest year is 2013	0.57	0.09
Pretest year is 2014	0.81	0.13
Pretest year is 2015	1.10	0.17
District percent rural	-0.26	0.06
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.39	0.58
Imputed for English learner status	-1.38	0.64
Imputed for baseline score	-0.03	0.02
Constant	-0.75	0.07
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C38. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with alternate control variable specifications – English language arts

	Estimate	SE
Virtual Virginia course	-0.24	0.12
Baseline score	2.30	0.02
Grade 10	0.83	0.19
Grade 11	1.66	0.20
Grade 12	1.63	0.22
Outcome year is 2016/17	-0.08	0.06
Student age	-0.54	0.02
Male	-0.01	0.02
Black/African American	-0.66	0.04
Hispanic	-0.02	0.04
Asian	0.22	0.06
Economically disadvantaged	-0.50	0.03
Gifted	0.01	0.62
English learner	-0.88	0.05
Receives special education services	-1.07	0.03
Pretest year is 2012	-0.24	0.08
Pretest year is 2013	-0.25	0.12
Pretest year is 2014	-0.36	0.19
Pretest year is 2015	0.61	0.50
District percent rural	-0.18	0.06
Imputed for race, age, economic disadvantage, gifted, special education status, and male	<0.01	1.20
Imputed for English learner status	-1.19	1.23
Imputed for baseline score	-0.37	0.03
Constant	0.28	0.15
Number of enrollments		
Virtual Virginia	964	
Face to face	128,049	
Total	129,013	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C39. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with alternate control variable specifications – Science

	Estimate	SE
Virtual Virginia course	-1.06	0.09
Baseline score	2.33	0.02
Grade 10	0.89	0.05
Grade 11	1.34	0.09
Grade 12	1.94	0.13
Outcome test is chemistry	0.03	0.04
Outcome test is earth science	0.13	0.04
Outcome year is 2016/17	-0.32	0.04
Student age	-0.51	0.01
Male	0.03	0.01
Black/African American	-0.75	0.03
Hispanic	-0.31	0.03
Asian	0.48	0.04
Economically disadvantaged	-0.49	0.02
Gifted	0.57	0.82
English learner	-0.63	0.04
Receives special education services	-0.93	0.02
Pretest year is 2012	0.18	0.08
Pretest year is 2013	0.60	0.11
Pretest year is 2014	1.02	0.14
Pretest year is 2015	1.30	0.17
District percent rural	-0.04	0.04
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.69	0.53
Imputed for English learner status	-0.56	0.58
Imputed for baseline score	-0.06	0.04
Constant	-0.10	0.03
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement outcomes

Results of the sensitivity analyses for courses with AP exams follow.

Advanced Placement test scores

The results for the sensitivity analyses based on the *z*-score translation of continuous AP exam scores are in exhibits C40 to C44.

Exhibit C40. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with alternate control variable specifications – Mathematics

	Estimate	SE
Virtual Virginia course	-0.33	0.07
Baseline score	0.42	0.01
Grade 10	-0.06	0.11
Grade 11	-0.15	0.14
Grade 12	-0.04	0.16
Outcome test is calculus AB	-0.12	0.05
Outcome test is calculus BC	-0.30	0.05
Outcome test is computer science	-0.33	0.07
Outcome year is 2016/17	-0.03	0.02
Student age	-0.14	0.02
Male	0.13	0.01
Black/African American	-0.33	0.03
Hispanic	-0.17	0.03
Asian	0.01	0.03
Economically disadvantaged	-0.22	0.03
Gifted	N/A	
English learner	0.05	0.05
Receives special education services	0.13	0.04
Pretest is algebra I	0.48	0.04
Pretest is geometry	0.93	0.05
Pretest year is 2013	0.08	0.04
Pretest year is 2014	0.32	0.07
Pretest year is 2015	0.40	0.20
District percent rural	-0.12	0.06
Imputed for baseline score	0.02	0.07
Constant	-0.48	0.06
Number of enrollments		
Virtual Virginia	296	
Face to face	29,846	
Total	30,142	

N/A is not applicable.

Notes: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C41. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with alternate control variable specifications – English language arts

	Estimate	SE
Virtual Virginia course	-0.01	0.07
Baseline score	0.47	0.01
Grade 10	1.60	0.23
Grade 11	1.69	0.19
Grade 12	2.15	0.20
Outcome subject is English language	0.33	0.14
Outcome year is 2016/17	-0.04	0.03
Student age	-0.11	0.01
Male	-0.01	0.01
Black/African American	-0.38	0.03
Hispanic	-0.13	0.02
Asian	0.14	0.03
Economically disadvantaged	-0.31	0.02
Gifted	0.95	0.18
English learner	-0.14	0.05
Receives special education services	-0.01	0.03
Pretest year is 2013	0.06	0.03
Pretest year is 2014	-0.04	0.19
Pretest year is 2015	1.18	0.54
District percent rural	-0.21	0.05
Imputed for baseline score	0.14	0.02
Constant	-0.18	0.06
Number of enrollments		
Virtual Virginia	291	
Face to face	41,835	
Total	42,126	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C42. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with alternate control variable specifications – Science

	Estimate	SE
Virtual Virginia course	-0.22	0.07
Baseline score	0.52	0.01
Grade 10	0.41	0.12
Grade 11	0.41	0.11
Grade 12	0.53	0.13
Outcome test is biology	0.17	0.05
Outcome test is environmental science	0.27	0.06
Outcome year is 2016/17	0.05	0.03
Student age	-0.11	0.01
Male	0.17	0.02
Black/African American	-0.42	0.03
Hispanic	-0.20	0.03
Asian	-0.01	0.03
Economically disadvantaged	-0.23	0.02
Gifted	N/A	
English learner	0.09	0.05
Receives special education services	0.04	0.03
Pretest year is 2013	0.02	0.03
Pretest year is 2014	0.08	0.06
Pretest year is 2015	0.08	0.10
District percent rural	-0.21	0.06
Imputed for baseline score	0.01	0.04
Constant	-0.14	0.04
Number of enrollments		
Virtual Virginia	437	
Face to face	27,859	
Total	28,296	

N/A is not applicable.
In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C43. Full model output for the relationship between Virtual Virginia and Advanced Placement score outcomes with alternate control variable specifications – History and social science

	Estimate	SE
Virtual Virginia course	-0.28	0.05
Baseline score	0.46	0.01
Grade 10	0.27	0.09
Grade 11	0.40	0.10
Grade 12	0.46	0.11
Outcome test is art history	-0.03	0.10
Outcome test is European history	-0.01	0.06
Outcome test is comparative government	0.02	0.07
Outcome test is U.S. government	-0.03	0.06
Outcome test is human geography	0.15	0.05
Outcome test is macroeconomics	-0.29	0.10
Outcome test is microeconomics	-0.19	0.09
Outcome test is psychology	0.09	0.06
Outcome test is U.S. history	-0.04	0.06
Outcome year is 2016/17	0.01	0.02
Student age	-0.09	0.01
Male	0.14	0.01
Black/African American	-0.35	0.03
Hispanic	-0.16	0.02
Asian	0.14	0.03
Economically disadvantaged	-0.28	0.02
Gifted	0.85	0.59
English learner	-0.06	0.03
Receives special education services	<0.01	0.02
Pretest year is 2013	-0.02	0.02
Pretest year is 2014	-0.02	0.04
Pretest year is 2015	-0.04	0.08
District percent rural	-0.15	0.06
Imputed for baseline score	0.10	0.02
Constant	0.01	0.04
Number of enrollments		
Virtual Virginia	2,143	
Face to face	106,974	
Total	109,117	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C44. Full model output for the relationship between Virtual Virginia and Advanced Placement score outcomes with alternate control variable specifications – Languages

	Estimate	SE
Virtual Virginia course	-0.24	0.18
Baseline score	0.30	0.02
Grade 11	-0.20	0.20
Grade 12	-0.23	0.21
Outcome test is Chinese	-0.19	0.16
Outcome test is French	0.09	0.09
Outcome test is Latin	-0.01	0.13
Outcome year is 2016/17	-0.25	0.19
Student age	-0.16	0.04
Male	-0.02	0.04
Black/African American	-0.27	0.08
Hispanic	0.58	0.06
Asian	0.12	0.12
Economically disadvantaged	0.02	0.05
Gifted	0.92	0.31
English learner	0.34	0.07
Receives special education services	-0.22	0.08
Pretest year is 2013	0.01	0.16
Pretest year is 2014	<0.01	0.20
District percent rural	-0.20	0.11
Imputed for baseline score	0.29	0.05
Constant	-0.03	0.11
Number of enrollments		
Virtual Virginia	136	
Face to face	3,417	
Total	3,553	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement proficiency

The results for the sensitivity analyses based on the dichotomization of AP exam scores are in exhibits C45 to C49.

Exhibit C45. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcome with alternate control variable specifications – Mathematics

	Estimate	SE
Virtual Virginia course	-0.76	0.18
Baseline score	0.92	0.03
Grade 10	-0.71	1.03
Grade 11	-0.86	1.13
Grade 12	-0.60	1.18
Outcome test is calculus AB	0.17	0.10
Outcome test is calculus BC	0.72	0.11
Outcome test is computer science	0.05	0.16
Outcome year is 2016/17	-0.20	0.05
Student age	-0.28	0.05
Male	0.27	0.03
Black/African American	-0.75	0.09
Hispanic	-0.39	0.06
Asian	<0.01	0.06
Economically disadvantaged	-0.54	0.07
Gifted	N/A	
English learner	0.09	0.14
Receives special education services	0.39	0.11
Pretest is algebra I	1.24	0.14
Pretest is geometry	2.17	0.16
Pretest year is 2013	0.24	0.09
Pretest year is 2014	0.95	0.20
Pretest year is 2015	0.36	1.61
District percent rural	-0.22	0.12
Imputed for baseline score	0.09	0.17
Constant	-0.87	0.17
Number of enrollments		
Virtual Virginia	296	
Face to face	29,846	
Total	30,142	

N/A is not applicable.
Notes: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C46. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with alternate control variable specifications – English language arts

	Estimate	SE
Virtual Virginia course	0.10	0.16
Baseline score	1.12	0.02
Grade 10	14.19	0.72
Grade 11	14.65	0.73
Grade 12	15.42	0.61
Outcome subject is English language	0.55	0.28
Outcome year is 2016/17	-0.15	0.06
Student age	-0.25	0.04
Male	0.01	0.03
Black/African American	-0.81	0.07
Hispanic	-0.25	0.06
Asian	0.36	0.08
Economically disadvantaged	-0.72	0.06
Gifted	N/A	
English learner	-0.65	0.15
Receives special education services	-0.09	0.09
Pretest year is 2013	0.24	0.07
Pretest year is 2014	-0.34	0.52
Pretest year is 2015	13.73	1.15
District percent rural	-0.40	0.11
Imputed for baseline score	0.32	0.06
Constant	0.23	0.13
Number of enrollments		
Virtual Virginia	291	
Face to face	41,834	
Total	42,125	

N/A is not applicable.

Notes: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C47. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with alternate control variable specifications – Science

	Estimate	SE
Virtual Virginia course	-0.62	0.17
Baseline score	1.25	0.03
Grade 10	0.84	0.24
Grade 11	0.97	0.33
Grade 12	1.22	0.35
Outcome test is biology	2.10	0.13
Outcome test is environmental science	1.27	0.15
Outcome year is 2016/17	0.39	0.07
Student age	-0.27	0.04
Male	0.43	0.04
Black/African American	-1.13	0.09
Hispanic	-0.49	0.08
Asian	-0.07	0.05
Economically disadvantaged	-0.64	0.07
Gifted	N/A	
English learner	0.11	0.16
Receives special education services	0.08	0.08
Pretest year is 2013	-0.05	0.08
Pretest year is 2014	0.09	0.18
Pretest year is 2015	0.06	0.27
District percent rural	-0.40	0.12
Imputed for baseline score	0.05	0.08
Constant	-0.97	0.11
Number of enrollments		
Virtual Virginia	456	
Face to face	28,022	
Total	28,478	

N/A is not applicable.

Notes: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C48. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with alternate control variable specifications – History and social science

	Estimate	SE
Virtual Virginia course	-0.67	0.10
Baseline score	1.05	0.02
Grade 10	0.57	0.21
Grade 11	0.87	0.24
Grade 12	0.86	0.26
Outcome test is art history	0.05	0.26
Outcome test is European history	-0.86	0.14
Outcome test is comparative government	-0.64	0.16
Outcome test is U.S. government	-0.30	0.13
Outcome test is human geography	-0.07	0.12
Outcome test is macroeconomics	-0.35	0.22
Outcome test is microeconomics	-0.12	0.20
Outcome test is psychology	0.27	0.13
Outcome test is U.S. history	-0.55	0.13
Outcome year is 2016/17	0.11	0.04
Student age	-0.21	0.02
Male	0.36	0.03
Black/African American	-0.75	0.07
Hispanic	-0.36	0.05
Asian	0.26	0.07
Economically disadvantaged	-0.57	0.05
Gifted	N/A	
English learner	-0.13	0.08
Receives special education services	<0.01	0.05
Pretest year is 2013	-0.21	0.05
Pretest year is 2014	-0.13	0.10
Pretest year is 2015	-0.33	0.20
District percent rural	-0.26	0.11
Imputed for baseline score	0.22	0.04
Constant	0.85	0.09
Number of enrollments		
Virtual Virginia	2,143	
Face to face	106,973	
Total	109,116	

N/A is not applicable.

Notes: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C49. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with alternate control variable specifications – Languages

	Estimate	SE
Virtual Virginia course	-0.51	0.41
Baseline score	0.69	0.09
Grade 10	13.61	1.23
Grade 11	0.13	0.92
Grade 12	0.45	0.53
Outcome test is Chinese	-0.33	0.58
Outcome test is French	-1.24	0.23
Outcome test is Latin	-2.10	0.27
Outcome year is 2016/17	-0.93	0.60
Student age	-0.36	0.14
Male	-0.20	0.11
Black/African American	-0.88	0.22
Hispanic	1.13	0.22
Asian	0.41	0.23
Economically disadvantaged	-0.25	0.19
Gifted	N/A	
English learner	1.39	0.41
Receives special education services	-0.36	0.29
Pretest year is 2013	0.24	0.70
Pretest year is 2014	-12.35	1.19
District percent rural	-0.35	0.25
Imputed for baseline score	0.51	0.20
Constant	3.40	0.26
Number of enrollments		
Virtual Virginia	136	
Face to face	3,416	
Total	3,552	

N/A is not applicable.
Notes: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Full model results with interaction terms for Standards of Learning outcomes

The coefficients (estimates) and standard errors for all variables included in the models used to estimate the relationship between taking a course online through VVA and SOL exam outcomes are in exhibits C50 to C53, including an interaction term for the student's grade level and the course the student took. The first row of each table displays the coefficient of interest: the relationship between VVA and the test outcome. Subsequent rows display each of the control variables in the model and the number of enrollments in that model. These models counted number of enrollments rather than number of students because a student may have been enrolled in more than one course in a subject area. (Exhibits C2 to C17 present the results of a sensitivity test aggregating results to the student level.) No substantive differences were found in the estimates of the relationship between VVA and test score outcomes.

Standards of Learning test scores

This section includes the linear regression results estimating the relationship between Virtual Virginia and SOL *z*-scores, including an interaction term for the student's grade level and the course the student took.

Exhibit C50. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with a grade-by-course interaction term – Mathematics

	Estimate	SE
Virtual Virginia course	-0.46	0.04
Baseline score	0.47	0.01
Grade 9	-0.18	0.03
Grade 10	-0.20	0.05
Grade 11	-0.11	0.06
Grade 12	0.04	0.10
Outcome test is algebra II	-0.08	0.02
Outcome test is geometry	0.04	0.01
Outcome year is 2016/17	0.02	0.02
Student age	-0.10	<0.01
Male	-0.01	<0.01
Black/African American	-0.14	0.01
Hispanic	-0.05	0.01
Asian	0.19	0.01
Economically disadvantaged	-0.12	0.01
Gifted	0.27	0.01
English learner	0.00	0.01
Receives special education services	-0.13	0.01
Pretest is algebra I	0.42	0.03
Pretest is geometry	0.69	0.07
Pretest is mathematics 8	0.09	0.03
Pretest year is 2012	0.10	0.02
Pretest year is 2013	0.21	0.04
Pretest year is 2014	0.33	0.06
Pretest year is 2015	0.36	0.07
District percent rural	-0.09	0.02
Imputed for race, age, economic disadvantage, gifted, special education status, and male	0.01	0.16
Imputed for English learner status	-1.00	0.16
Imputed for baseline score	0.09	0.01
Grade 9*algebra II interaction	0.62	0.08
Grade 9*geometry interaction	0.46	0.05
Grade 10*algebra II interaction	0.51	0.05
Grade 10*geometry interaction	0.28	0.04
Grade 11*algebra II interaction	0.22	0.04
Grade 11*geometry interaction	0.12	0.04
Constant	-0.21	0.02
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C51. Full model results for the relationship between Virtual Virginia and Standards of Learning score outcomes with a grade-by-course interaction term – Science

	Estimate	SE
Virtual Virginia course	-0.34	0.03
Baseline score	0.61	0.01
Grade 10	0.14	0.01
Grade 11	0.22	0.03
Grade 12	0.34	0.04
Outcome test is chemistry	-0.16	0.02
Outcome test is earth science	0.21	0.01
Outcome year is 2016/17	-0.03	0.01
Student age	-0.13	<0.01
Male	-0.01	<0.01
Black/African American	-0.19	0.01
Hispanic	-0.07	0.01
Asian	0.13	0.01
Economically disadvantaged	-0.13	0.01
Gifted	0.29	0.01
English learner	-0.12	0.01
Receives special education services	-0.19	0.01
Pretest year is 2012	0.17	0.02
Pretest year is 2013	0.27	0.03
Pretest year is 2014	0.36	0.04
Pretest year is 2015	0.41	0.05
District percent rural	-0.07	0.01
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.20	0.39
Imputed for English learner status	-0.55	0.40
Imputed for baseline score	-0.01	0.01
Grade 10*chemistry interaction	-0.08	0.03
Grade 10*earth science interaction	0.03	0.02
Grade 11*chemistry interaction	-0.19	0.04
Grade 11*earth science interaction	0.16	0.03
Grade 12*chemistry interaction	-0.27	0.04
Grade 12*earth science interaction	0.17	0.03
Constant	-0.03	0.01
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from SOL scaled scores. *Z*-scores were created by taking each student's SOL scaled score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Standards of Learning proficiency

The logistic regression results estimating the relationship between VVA and proficiency on the SOL exam (a score of 400 or higher) are in exhibits C52 and C53, including an interaction term for the student's grade level and the course the student took.

Exhibit C52. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with a grade-by-course interaction term – Mathematics

	Estimate	SE
Virtual Virginia course	-1.47	0.14
Baseline score	1.51	0.02
Grade 9	-0.49	0.11
Grade 10	-0.44	0.13
Grade 11	0.09	0.16
Grade 12	0.75	0.23
Outcome test is algebra II	0.68	0.08
Outcome test is geometry	0.03	0.05
Outcome year is 2016/17	-0.28	0.05
Student age	-0.33	0.01
Male	-0.08	0.01
Black/African American	-0.51	0.04
Hispanic	-0.18	0.04
Asian	0.46	0.04
Economically disadvantaged	-0.42	0.02
Gifted	0.97	0.04
English learner	-0.09	0.04
Receives special education services	-0.58	0.03
Pretest is algebra I	0.79	0.11
Pretest is geometry	0.93	0.23
Pretest is math8	0.44	0.10
Pretest year is 2012	0.28	0.06
Pretest year is 2013	0.62	0.10
Pretest year is 2014	0.88	0.15
Pretest year is 2015	1.19	0.19
District percent rural	-0.25	0.06
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.56	0.50
Imputed for English learner status	-1.25	0.55
Imputed for baseline score	-0.06	0.02
Grade 9*algebra II interaction	0.92	0.27
Grade 9*geometry interaction	0.97	0.16
Grade 10*algebra II interaction	1.05	0.14
Grade 10*geometry interaction	0.91	0.15
Grade 11*algebra II interaction	0.48	0.14
Grade 11*geometry interaction	0.35	0.15
Constant	-0.46	0.07
Number of enrollments		
Virtual Virginia	1,765	
Face to face	381,970	
Total	383,735	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C53. Full model results for the relationship between Virtual Virginia and Standards of Learning proficiency outcomes with a grade-by-course interaction term – Science

	Estimate	SE
Virtual Virginia course	-1.17	0.08
Baseline score	2.21	0.02
Grade 10	0.74	0.06
Grade 11	1.20	0.09
Grade 12	2.01	0.13
Outcome test is chemistry	0.16	0.14
Outcome test is earth science	0.29	0.04
Outcome year is 2016/17	-0.30	0.04
Student age	-0.48	0.01
Male	0.04	0.01
Black/African American	-0.71	0.03
Hispanic	-0.29	0.03
Asian	0.40	0.04
Economically disadvantaged	-0.52	0.02
Gifted	1.52	0.08
English learner	-0.59	0.04
Receives special education services	-0.90	0.02
Pretest year is 2012	0.17	0.08
Pretest year is 2013	0.59	0.11
Pretest year is 2014	1.00	0.13
Pretest year is 2015	1.28	0.16
District percent rural	-0.04	0.04
Imputed for race, age, economic disadvantage, gifted, special education status, and male	-0.50	0.50
Imputed for English learner status	-0.80	0.54
Imputed for baseline score	-0.08	0.04
Grade 10*chemistry interaction	-0.08	0.32
Grade 10*earth science interaction	0.19	0.07
Grade 11*chemistry interaction	-0.26	0.32
Grade 11*earth science interaction	0.77	0.09
Grade 12*chemistry interaction	-0.68	0.33
Grade 12*earth science interaction	0.91	0.12
Constant	0.15	0.03
Number of enrollments		
Virtual Virginia	1,874	
Face to face	417,792	
Total	419,666	

Note: In this analysis, SOL proficiency was used as an outcome. SOL scaled scores range from 0 to 600, where a score of 0–399 means a student did not pass the test. A score of 400–499 means a student passed a test and was classified as proficient, and a score of 500–600 means a student passed a test and was classified as advanced. The outcome used in these analyses is dichotomous, with scores of 400 or above scored as 1 and scores of 399 and below scored as 0.

Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Full model results with interaction terms for Advanced Placement outcomes

This section shows the coefficients (estimates) and standard errors for all variables included in the models used to estimate the relationship between VVA and AP exam outcomes, including an interaction term for the student's grade level and the course he or she took. The first row displays the coefficient of interest: the relationship between VVA and the test outcome. Subsequent rows display each of the control variables in the model and the number of enrollments in that model. These models count number of enrollments rather than number of students because a student may have been enrolled in more than one course in a subject area. (Exhibits C2 to C17 present the results of a sensitivity test aggregating results to the student level.)

Advanced Placement test scores

The linear regression results estimating the relationship between Virtual Virginia and AP *z*-scores are in exhibits C54–C58, including an interaction term for the student's grade level and the course the student took.

Exhibit C54. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with a grade-by-course interaction term – Mathematics

	Estimate	SE
Virtual Virginia course	-0.34	0.07
Baseline score	0.39	0.01
Grade 10	0.43	0.47
Grade 11	0.41	0.43
Grade 12	0.52	0.44
Outcome test is calculus AB	-0.06	0.05
Outcome test is calculus BC	-0.31	0.07
Outcome test is computer science	-0.32	0.07
Outcome year is 2016/17	-0.03	0.02
Student age	-0.14	0.02
Male	0.13	0.01
Black/African American	-0.31	0.03
Hispanic	-0.15	0.03
Asian	0.02	0.03
Economically disadvantaged	-0.21	0.03
Gifted	0.19	0.02
English learner	0.10	0.05
Receives special education services	0.12	0.04
Pretest is algebra I	0.42	0.04
Pretest is geometry	0.82	0.06
Pretest year is 2013	0.09	0.04
Pretest year is 2014	0.31	0.07
Pretest year is 2015	0.38	0.18
District percent rural	-0.11	0.06
Imputed for baseline score	-0.01	0.05
Grade 10*calculus AB interaction	-0.95	0.60
Grade 10*computer science interaction	-0.57	0.54
Grade 11*calculus AB interaction	-1.19	0.55
Grade 11*calculus BC interaction	-0.08	0.24
Grade 11*computer science interaction	-0.61	0.48
Grade 12*calculus AB interaction	-1.20	0.56
Grade 12*calculus BC interaction	-0.03	0.26
Grade 12*computer science interaction	-0.68	0.49
Constant	-0.45	0.06
Number of enrollments		
Virtual Virginia	296	
Face to face	29,846	
Total	30,142	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C55. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with a grade-by-course interaction term – English language arts

	Estimate	SE
Virtual Virginia course	-0.06	0.07
Baseline score	0.40	0.01
Grade 10	-0.89	0.34
Grade 11	-0.02	0.48
Grade 12	0.34	0.46
Outcome subject is English language	0.35	0.11
Outcome year is 2016/17	-0.04	0.03
Student age	-0.11	0.01
Male	-0.04	0.01
Black/African American	-0.34	0.03
Hispanic	-0.11	0.02
Asian	0.14	0.03
Economically disadvantaged	-0.29	0.02
Gifted	0.39	0.02
English learner	-0.09	0.05
Receives special education services	-0.03	0.03
Pretest year is 2013	0.06	0.03
Pretest year is 2014	0.13	0.26
Pretest year is 2015	1.09	0.52
District percent rural	-0.19	0.05
Imputed for baseline score	0.26	0.02
Grade 10*ELA interaction	2.56	0.41
Grade 11*ELA interaction	1.84	0.41
Grade 12*ELA interaction	1.96	0.42
Constant	-0.18	0.07
Number of enrollments		
Virtual Virginia	291	
Face to face	41,835	
Total	42,126	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C56. Full model results for the relationship between Virtual Virginia and Advanced Placement score outcomes with a grade-by-course interaction term – Science

	Estimate	SE
Virtual Virginia course	-0.27	0.06
Baseline score	0.47	0.01
Grade 10	0.29	0.56
Grade 11	-0.07	0.55
Grade 12	-0.04	0.55
Outcome test is biology	0.15	0.05
Outcome test is environmental science	0.24	0.05
Outcome year is 2016/17	0.05	0.03
Student age	-0.12	0.01
Male	0.18	0.02
Black/African American	-0.40	0.03
Hispanic	-0.19	0.02
Asian	-0.02	0.03
Economically disadvantaged	-0.21	0.02
Gifted	0.28	0.02
English learner	0.15	0.05
Receives special education services	0.02	0.03
Pretest year is 2013	0.00	0.03
Pretest year is 2014	0.04	0.06
Pretest year is 2015	0.07	0.10
District percent rural	-0.20	0.06
Imputed for baseline score	0.06	0.03
Grade 10*biology interaction	0.30	0.64
Grade 10*environmental science interaction	0.04	0.65
Grade 11*biology interaction	0.68	0.61
Grade 11*environmental science interaction	0.56	0.63
Grade 12*biology interaction	0.80	0.61
Grade 11*environmental science interaction	0.71	0.63
Constant	-0.12	0.04
Number of enrollments		
Virtual Virginia	437	
Face to face	27,859	
Total	28,296	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C57. Full model output for the relationship between Virtual Virginia and Advanced Placement score outcomes with a grade-by-course interaction term – History and social science

	Estimate	SE
Virtual Virginia course	-0.34	0.05
Baseline score	0.40	0.01
Grade 10	0.27	0.17
Grade 11	0.46	0.18
Grade 12	0.60	0.20
Outcome test is art history	-0.14	0.09
Outcome test is European history	0.13	0.08
Outcome test is comparative government	0.00	0.08
Outcome test is U.S. government	-0.24	0.07
Outcome test is human geography	0.06	0.07
Outcome test is macroeconomics	-0.41	0.09
Outcome test is microeconomics	-0.27	0.08
Outcome test is psychology	-0.01	0.07
Outcome test is U.S. history	-0.14	0.08
Outcome year is 2016/17	0.01	0.02
Student age	-0.10	0.01
Male	0.13	0.01
Black/African American	-0.31	0.03
Hispanic	-0.13	0.02
Asian	0.13	0.03
Economically disadvantaged	-0.26	0.02
Gifted	0.34	0.01
English learner	-0.03	0.03
Receives special education services	-0.01	0.02
Pretest year is 2013	-0.02	0.02
Pretest year is 2014	-0.01	0.04
Pretest year is 2015	-0.01	0.08
District percent rural	-0.14	0.05
Imputed for baseline score	0.19	0.01
Grade 10*art history interaction	-0.67	0.36
Grade 10*European history interaction	0.03	0.28
Grade 10*U.S. government interaction	-0.46	0.38
Grade 10*human geography interaction	-0.19	0.24
Grade 10*macroeconomics interaction	-0.55	0.44
Grade 10*microeconomics interaction	-0.67	0.32
Grade 10*psychology interaction	-0.09	0.28
Grade 10*U.S. history interaction	-0.45	0.41
Grade 11*art history interaction	-0.78	0.27
Grade 11*European history interaction	0.35	0.28
Grade 11*comparative government and politics interaction	0.17	0.16
Grade 11*U.S. government interaction	-0.97	0.38
Grade 11*human geography interaction	-0.22	0.24
Grade 11*macroeconomics interaction	-0.69	0.42
Grade 11*microeconomics interaction	-0.99	0.29
Grade 11*psychology interaction	-0.28	0.28
Grade 11*U.S. history interaction	-0.33	0.38
Constant	-0.87	0.28

Number of enrollments	
Virtual Virginia	2,143
Face to face	106,974
Total	109,117

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C58. Full model output for the relationship between Virtual Virginia and Advanced Placement score outcomes with a grade-by-course interaction term – Languages

	Estimate	SE
Virtual Virginia course	-0.19	0.18
Baseline score	0.28	0.02
Grade 11	-0.28	0.22
Grade 12	-0.19	0.22
Outcome test is Chinese	-0.19	0.17
Outcome test is French	0.09	0.09
Outcome test is Latin	-0.02	0.14
Outcome year is 2016/17	-0.21	0.18
Student age	-0.17	0.04
Male	-0.02	0.04
Black/African American	-0.25	0.09
Hispanic	0.62	0.06
Asian	0.12	0.11
Economically disadvantaged	-0.03	0.07
Gifted	0.14	0.04
English learner	0.36	0.07
Receives special education services	-0.28	0.08
Pretest year is 2013	0.07	0.18
Pretest year is 2014	0.02	0.19
District percent rural	-0.19	0.10
Imputed for baseline score	0.33	0.06
Grade 11*Chinese interaction	0.08	0.23
Grade 11*French interaction	0.16	0.21
Grade 11*Latin interaction	0.13	0.35
Grade 12*Chinese interaction	0.09	0.25
Grade 12*French interaction	-0.05	0.24
Grade 12*Latin interaction	0.04	0.23
Constant	-0.06	0.11
Number of enrollments		
Virtual Virginia	136	
Face to face	3,417	
Total	3,553	

Note: In this analysis, *z*-scores were used as an outcome and baseline test measure, derived from AP exam scores. *Z*-scores were created by taking each student's AP exam score and subtracting the mean and dividing it by the standard deviation. *Z*-scores have a mean of 0 and a standard deviation of 1. A negative number indicates that the student was below the average for his or her grade level and school year, whereas a positive number indicates that a student was above average for his or her grade level and school year. Average *z*-scores for the overall population are always zero.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Advanced Placement proficiency

The logistic regression results estimating the relationship between VVA and AP proficiency (a score of 3 or higher) are in exhibits C59–C62, including an interaction term for the student's grade level and the course the student took.

Exhibit C59. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with a grade-by-course interaction term – Mathematics

	Estimate	SE
Virtual Virginia course	-0.80	0.18
Baseline score	0.87	0.03
Grade 10	-0.33	1.70
Grade 11	-0.38	1.70
Grade 12	-0.05	1.71
Outcome test is calculus AB	0.59	0.14
Outcome test is calculus BC	0.63	0.20
Outcome test is computer science	0.11	0.17
Outcome year is 2016/17	-0.21	0.05
Student age	-0.29	0.05
Male	0.28	0.03
Black/African American	-0.71	0.09
Hispanic	-0.36	0.07
Asian	0.03	0.06
Economically disadvantaged	-0.51	0.07
Gifted	0.42	0.04
English learner	0.21	0.14
Receives special education services	0.36	0.11
Pretest is algebra I	1.09	0.14
Pretest is geometry	1.92	0.17
Pretest year is 2013	0.25	0.09
Pretest year is 2014	0.95	0.20
Pretest year is 2015	0.20	1.68
District percent rural	-0.21	0.12
Imputed for baseline score	0.02	0.14
Grade 10*calculus AB interaction	-12.46	2.03
Grade 10*calculus BC interaction	-0.45	1.08
Grade 10*computer science interaction	-1.68	1.70
Grade 11*calculus AB interaction	-13.49	2.01
Grade 11*calculus BC interaction	-0.07	0.21
Grade 11*computer science interaction	-1.68	1.67
Grade 12*calculus AB interaction	-13.50	2.06
Grade 12*computer science interaction	-2.01	1.71
Constant	-0.79	0.17
Number of enrollments		
Virtual Virginia	296	
Face to face	29,846	
Total	30,142	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C60. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with a grade-by-course interaction term – Science

	Estimate	SE
Virtual Virginia course	-0.70	0.16
Baseline score	1.13	0.03
Grade 10	0.54	1.61
Grade 11	-0.07	1.59
Grade 12	0.03	1.60
Outcome test is biology	2.10	0.12
Outcome test is environmental science	1.24	0.13
Outcome year is 2016/17	0.38	0.07
Student age	-0.28	0.04
Male	0.45	0.04
Black/African American	-1.12	0.08
Hispanic	-0.45	0.08
Asian	-0.08	0.05
Economically disadvantaged	-0.59	0.07
Gifted	0.64	0.05
English learner	0.22	0.16
Receives special education services	0.01	0.08
Pretest year is 2013	-0.07	0.07
Pretest year is 2014	0.02	0.17
Pretest year is 2015	0.05	0.27
District percent rural	-0.39	0.12
Imputed for baseline score	0.17	0.08
Grade 10*biology interaction	0.10	1.58
Grade 10*environmental science interaction	0.23	1.86
Grade 11*biology interaction	0.94	1.59
Grade 11*environmental science interaction	1.27	1.85
Grade 12*biology interaction	1.17	1.59
Grade 12*environmental science interaction	1.54	1.84
Constant	-0.95	0.10
Number of enrollments		
Virtual Virginia	456	
Face to face	28,022	
Total	28,478	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C61. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with a grade-by-course interaction term – History and social science

	Estimate	SE
Virtual Virginia course	-0.76	0.10
Baseline score	0.94	0.02
Grade 10	0.68	0.22
Grade 11	1.08	0.25
Grade 12	1.07	0.26
Outcome test is art history	-0.04	0.26
Outcome test is European history	-0.90	0.14
Outcome test is comparative government	-0.66	0.17
Outcome test is U.S. government	-0.37	0.13
Outcome test is human geography	-0.09	0.12
Outcome test is macroeconomics	-0.48	0.22
Outcome test is microeconomics	-0.18	0.20
Outcome test is psychology	0.25	0.13
Outcome test is U.S. history	-0.61	0.14
Outcome year is 2016/17	0.11	0.04
Student age	-0.22	0.02
Male	0.33	0.03
Black/African American	-0.69	0.06
Hispanic	-0.31	0.05
Asian	0.26	0.06
Economically disadvantaged	-0.56	0.05
Gifted	0.70	0.03
English learner	-0.04	0.08
Receives special education services	-0.03	0.05
Pretest year is 2013	-0.20	0.05
Pretest year is 2014	-0.11	0.10
Pretest year is 2015	-0.25	0.20
District percent rural	-0.24	0.11
Imputed for baseline score	0.38	0.04
Grade 10*art history interaction	-16.00	1.37
Grade 10*European history interaction	-0.06	0.61
Grade 10*comparative government and politics interaction	0.15	0.31
Grade 10*U.S. government interaction	-0.61	0.79
Grade 10*human geography interaction	-0.53	0.50
Grade 10*macroeconomics interaction	-0.66	0.72
Grade 10*microeconomics interaction	-13.80	1.13
Grade 10*psychology interaction	0.04	0.60
Grade 10*U.S. history interaction	-0.90	1.27
Grade 11*art history interaction	-15.99	1.20
Grade 11*European history interaction	0.49	0.60
Grade 11*comparative government and politics interaction	0.37	0.52
Grade 11*U.S. government interaction	-1.98	0.86
Grade 11*human geography interaction	-0.49	0.49
Grade 11*macroeconomics interaction	-1.24	0.65
Grade 11*microeconomics interaction	-14.86	1.07
Grade 11*psychology interaction	-0.32	0.55
Grade 11*U.S. history interaction	-0.64	1.25

Constant	-16.26	1.17
Number of enrollments		
Virtual Virginia	2,143	
Face to face	106,974	
Total	109,117	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

Exhibit C62. Full model output for the relationship between Virtual Virginia and Advanced Placement proficiency outcomes with a grade-by-course interaction term – Languages

	Estimate	SE
Virtual Virginia course	-0.49	0.41
Baseline score	0.66	0.08
Grade 11	14.68	1.53
Grade 12	-0.31	1.24
Outcome test is Chinese	0.04	0.85
Outcome test is French	1.64	0.61
Outcome test is Latin	-1.40	0.25
Outcome year is 2016/17	-2.20	0.28
Student age	-0.85	0.65
Male	-0.37	0.14
Black/African American	-0.22	0.11
Hispanic	-0.87	0.23
Asian	1.17	0.24
Economically disadvantaged	0.44	0.22
Gifted	-0.17	0.18
English learner	0.21	0.15
Receives special education services	1.34	0.38
Pretest year is 2013	-0.46	0.25
Pretest year is 2014	0.19	0.78
District percent rural	-13.38	1.42
Imputed for baseline score	-0.37	0.25
Grade 11*Chinese interaction	0.60	0.23
Grade 11*French interaction	-12.75	0.76
Grade 11*Latin interaction	1.98	0.67
Grade 12*Chinese interaction	0.25	0.92
Grade 12*French interaction	-11.88	1.01
Grade 12*Latin interaction	1.45	0.75
Constant	0.56	0.79
Number of enrollments		
Virtual Virginia	136	
Face to face	3,417	
Total	3,553	

Note: In this analysis, AP proficiency was used as an outcome. AP exam scores range from 1 to 5, where 3 is considered proficient. The outcome used in these analyses is dichotomous, with scores of 3 or higher scored as 1 and scores of 2 or lower scored as 0.
Source: Authors' analysis of administrative data provided by the Virginia Longitudinal Data System.

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