Online Appendix

The Educational Consequences of Remote and Hybrid Instruction During the Pandemic

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Appendix A: Explaining the Change in School Effects 2017-19 to 2019-21

To estimate how the variance of school effects changed between the pre-pandemic and pandemic periods, we use a two-step approach. We first estimated the following equation by OLS for 2017-19 and 2019-21:

(1) $S_{ij} = \beta_0 + X_{ij}\beta_4 + \delta_j + \varepsilon_{ij}$

where X includes all the student-level covariates and δ_j are school fixed effects. We then use the estimated school fixed effects plus the student-level residuals, $\hat{\delta}_j + \hat{\varepsilon}_i = S_{ij} - \hat{\beta}_0 + X_{ij}\hat{\beta}_4$, as the dependent variable in a simple hierarchical linear model for each year with only an intercept and school random effects, estimated using the xtreg command in Stata. This yields estimates of the variance of the underlying school $\left(\sigma_\mu^2\right)$ and student (σ_ε^2) error components in each year. If the pandemic introduced school-level shocks then the variance of school effects will be larger in 2021 than it was in 2019, e.g., $\sigma^2_{\mu,2021} > \sigma^2_{\mu,2019}$.

We then re-estimated the hierarchical models controlling for three school poverty categories, percent remote and hybrid, and their interactions. If school poverty and remote/hybrid instruction capture the pandemic-related school-level shocks, then the school-level variance estimate from this model should be lower in 2021 compared to a model that does not control for any school characteristics.

As can be seen from the table below, the variance in the school effect rose substantially between 17-19 and 19-21 for both math (.0202, 81% rise) and reading (.0133, 60% rise). Controlling for poverty and hybrid/remote explains little of the school-level variance in 17-19 but explains a much larger proportion of variation in 19-21. Overall, Controlling for poverty and

hybrid/remote accounted for 66% of the rise in school-level variance for math, and 57% for reading.

	Math			Reading		
	17-19	19-21	Change	17-19	19-21	Change
Variance of School Effect	0.0248	0.0450	0.0201	0.0220	0.0353	0.0133
Variance of School Effect Controlling for Poverty and Hybrid/Remote	0.0215	0.0283	0.0068	0.0189	0.0246	0.0058
% of Change in School Variance Accounted for by Poverty and Hybrid/Remote:			66%			57%

Appendix B:
Decomposing the Role of Disparate Incidence and Disparate Impacts of Remote/Hybrid instruction on Pandemic Achievement Differences between High and Low Poverty Schools

We use the parameters from Column (5) of Table 1 to identify the share of the widening attributable to multiple factors. Below, the subscript for each coefficient refers to the row number from Table 1.

$$\bar{R}_{Low} - \bar{R}_{Hgh} =$$

$$+\hat{\gamma}_1\left(\overline{Black}_{Low} - \overline{Black}_{Hgh}\right) + \hat{\gamma}_2\left(\overline{Hispanic}_{Low} - \overline{Hispanic}_{Hgh}\right) + \quad \text{(a)}$$
$$\hat{\gamma}_3\left(\overline{Asian}_{Low} - Asian_{Hgh}\right) + \hat{\gamma}_4\left(\overline{Other}_{Low} - \overline{Other}_{Hgh}\right) +$$
$$\hat{\gamma}_5\left(\overline{MidBase}_{Low} - \overline{MidBase}_{Hgh}\right) + \hat{\gamma}_6\left(\overline{LowBase}_{Low} - \overline{LowBase}_{Hgh}\right)$$

$$-\hat{\gamma}_8 \quad \text{(b)}$$

$$\left(\hat{\gamma}_{12} + \hat{\gamma}_{14}\right)\left(\overline{\%Hybrid}_{Low} - \overline{\%Hybrid}_{Hgh}\right) + \left(\hat{\gamma}_9 + \hat{\gamma}_{11}\right)\left(\overline{\%Remote}_{Low} - \overline{\%Remote}_{Hgh}\right) \quad \text{(c)}$$

$$-\hat{\gamma}_{14}\left(\overline{\%Hybrid}_{Low}\right) - \hat{\gamma}_{11}\left(\overline{\%Remote}_{Low}\right) \quad \text{(d)}$$

The first component, (a), captures the differences in student growth due to differences in the race/ethnicity and baseline achievement of students. The second component, (b), reflects the differential losses of high and low-poverty schools that were in person throughout 2020-21. The third component, (c), measures the effect of disparate incidence of remote and hybrid instruction, assessed as the impact of remote and hybrid instruction for high poverty schools. The fourth component, (d), is the largest component. It reflects the differential impact of remote schooling on high poverty schools.

Appendix Table 1:

Pandemic Achievement Gains by Student and School Characteristics, Reading

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Race (Reference: White)							
Black	-0.080		-0.062	-0.023	-0.019	-0.039	-0.018
	(0.009)		(0.008)	(0.005)	(0.005)	(0.005)	(0.005)
Hispanic	-0.066		-0.048	-0.030	-0.007	-0.039	-0.007
	(0.011)		(0.010)	(0.006)	(0.006)	(0.006)	(0.006)
Asian	0.018		0.013	-0.019	0.019	-0.017	0.019
	(0.010)		(0.010)	(0.006)	(0.008)	(0.006)	(0.008)
Other	-0.023		-0.016	-0.011	-0.005	-0.015	-0.005
	(0.006)		(0.006)	(0.006)	(0.005)	(0.006)	(0.005)
Baseline Score (Reference: Top Quartile)							
Middle Quartiles		-0.048	-0.039	-0.013	-0.030	-0.019	-0.031
		(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Bottom Quartile		-0.115	-0.098	-0.043	-0.076	-0.052	-0.076
		(0.008)	(0.006)	(0.005)	(0.004)	(0.005)	(0.004)
School Poverty (Reference: Low <25%)							
Middle (25%-75%)					-0.021	0.019	-0.020
					(0.009)	(0.015)	(0.009)
High (>75%)					-0.038	0.011	-0.037
					(0.016)	(0.023)	(0.016)
Remote Schooling							
% Remote in 2020-21					-0.081	N/A	-0.079
					(0.022)		(0.022)
Interactions:							
• Middle Poverty					-0.034	-0.081	-0.033
					(0.021)	(0.029)	(0.021)
• High Poverty					-0.094	-0.134	-0.096
					(0.040)	(0.037)	(0.040)
Hybrid Schooling							
% Hybrid in 2020-21					0.018	N/A	0.018
					(0.014)		(0.014)
Interactions:							
• Middle Poverty					-0.037	-0.008	-0.036
					(0.015)	(0.022)	(0.015)
• High Poverty					-0.074	-0.049	-0.075
					(0.024)	(0.037)	(0.024)
% Tested in School							0.025
							(0.018)
Constant	-0.093	-0.066	-0.056	N/A	-0.027	N/A	-0.050
	(0.004)	(0.003)	(0.003)		(0.009)		(0.019)
Fixed Effects?	No	No	No	School	No	District	No

Notes: Sample includes 1,665,350 students in grades 3-8 at the time of their follow-up test. Dependent variable is the difference between a student's standardized 2021 fall NWEA MAP score and their expected score based on baseline characteristics from two years earlier (2019). The parameters for predicting expected scores were drawn from a pre-pandemic regression of fall 2019 scores on baseline characteristics from 2017. Bootstrapped standard errors were estimated by resampling at the district level and re-estimating both equations (1) and (2) 1000 times.

Appendix Table 2:
Decomposing the Difference in Pandemic Achievement Gains between High and Low Poverty Schools, Reading

	Amount	*% of total*
Total Difference Between High and Low Poverty Schools	0.146	100%
Due to Direct Effects of:		
Race	0.008	5%
Baseline Scores	0.021	14%
Conditional Learning Loss in High Poverty Schools That Were Fully in Person	0.038	26%
Due to Differing Incidence of Remote and Hybrid Learning	0.027	19%
Due to Differing Effects of Remote and Hybrid Learning	0.052	35%

Notes**:** Decomposition based on regression estimates from Appendix Table 1, column 5, and based on mean characteristics of high and low poverty schools in the analysis sample used in Appendix Table 1. See Appendix B for details on the decomposition and Appendix Table 6 for mean characteristics of high and low poverty schools.

Appendix Table 3: Comparing the Analysis Sample to the Universe of K-8 Public Schools

	19-21 Analysis Sample, Math	19-21 Analysis Sample, Reading	CCD Grades 3-8
	Race		
White	52%	52%	46%
Black	13%	14%	15%
Hispanic	20%	19%	28%
Asian	4%	4%	5%
	Poverty level		
High	22%	22%	27%
Mid	54%	55%	54%
Low	24%	23%	20%
	Urbanicity		
City	25%	25%	30%
Rural	19%	20%	20%
Suburb	44%	43%	39%
Town	12%	12%	11%
	Learning Mode		
Mean % of Year Remote	21%	20%	24%
Mean % of Year Hybrid	47%	47%	46%
Mean NWEA Fall 2021 Normalized RIT Score	-0.11	-0.08	N/A
Number of Districts in Sample	1,727	1,726	16,470
Number of Schools in Sample	9,690	9,488	74,189
Number of Students in Sample	2,102,010	1,665,350	22,835,038

Notes: Analysis samples include students in NWEA test score data that (1) attend schools that test at least 10 students in fall 2017, fall 2019, and fall 2021; (2) attend schools that test at least 60% of their school-grade-level enrollment as reported in the Common Core of Data; and (3) have available data on the student's race, gender, school poverty level, and learning modality.

Appendix Table 4: 2017-19 Growth Model Parameters

	Math	Reading
Race (Reference: White)		
Black	-0.116	-0.112
	(0.006)	(0.006)
Hispanic	-0.024	-0.028
	(0.005)	(0.005)
Asian	0.195	0.136
	(0.007)	(0.006)
Other	-0.028	-0.033
	(0.005)	(0.006)
School Poverty (Reference: Low <25%)		
Middle (25%-75%)	-0.082	-0.077
	(0.010)	(0.011)
High (>75%)	-0.175	-0.141
	(0.017)	(0.015)
Linear Term of Baseline Score	0.757	0.729
	(0.004)	(0.005)
Remote Schooling		
% Remote in 2020-21	0.044	0.035
	(0.034)	(0.023)
Interactions:		
• Middle Poverty	-0.038	-0.015
	(0.028)	(0.022)
• High Poverty	-0.049	-0.075
	(0.031)	(0.025)
Hybrid Schooling		
% Hybrid in 2020-21	-0.007	-0.011
	(0.013)	(0.013)
Interactions:		
• Middle Poverty	-0.006	0.002
	(0.014)	(0.014)
• High Poverty	0.053	0.027
	(0.029)	(0.028)
All X's	Yes	Yes
School FE	No	No
District FE	No	No

Notes: Sample includes 2,313,077 students in math and 1,822,076 students in reading in grades 3-8. Dependent variable is the student's fall 2019 test score. The parameters for predicting expected scores in Table 1 and Appendix Table 4 are drawn from these regressions. Bootstrapped standard errors were estimated by resampling at the district level and re-estimating both equations (1) and (2) 1000 times.

Appendix Table 5: Predictors of Having a Follow-up Score

	2017-19		2019-21	
	Math	Reading	Math	Reading
Race (Reference: White)				
Black	-0.080	-0.055	-0.075	-0.049
	(0.029)	(0.027)	(0.015)	(0.016)
Hispanic	-0.015	-0.016	0.000	0.010
	(0.013)	(0.014)	(0.014)	(0.019)
Asian	-0.061	-0.049	-0.045	-0.010
	(0.014)	(0.013)	(0.010)	(0.016)
Other	-0.039	-0.044	-0.046	-0.045
	(0.011)	(0.009)	(0.015)	(0.013)
School Poverty (Reference: Low <25%)				
Middle (25%-75%)	-0.054	-0.036	-0.060	-0.073
	(0.024)	(0.026)	(0.025)	(0.025)
High (>75%)	-0.071	-0.043	-0.024	-0.030
	(0.030)	(0.032)	(0.028)	(0.029)
Linear Term of Baseline Score	0.014	-0.010	0.006	-0.039
	(0.004)	(0.007)	(0.004)	(0.011)
Remote Schooling				
% Remote in 2020-21	-0.069	-0.106	-0.235	-0.304
	(0.056)	(0.062)	(0.060)	(0.084)
Interactions:				
• Middle Poverty	0.011	0.002	0.212	0.117
	(0.070)	(0.067)	(0.047)	(0.094)
• High Poverty	-0.003	0.016	0.087	-0.022
	(0.077)	(0.074)	(0.092)	(0.098)
Hybrid Schooling				
% Hybrid in 2020-21	-0.016	-0.015	0.020	-0.027
	(0.042)	(0.043)	(0.025)	(0.028)
Interactions:				
• Middle Poverty	0.088	0.063	0.018	0.061
	(0.045)	(0.046)	(0.034)	(0.035)
• High Poverty	0.107	0.085	-0.064	-0.001
	(0.058)	(0.057)	(0.047)	(0.052)
All X's	Yes	Yes	Yes	Yes
School FE	No	No	No	No
District FE	No	No	No	No

Notes: Sample includes all students in grades 1-6 with a baseline score and non-missing independent variables. Dependent variable is whether the student had a follow-up score in either fall 2019 (in the 2017-19 regressions) or fall 2021 (in the 2019-21 regressions). Standard errors (clustered at the district level) in parentheses.

Appendix Table 6: Mean Student Characteristics by School Poverty

	Math		Reading	
	Low Poverty	High Poverty	Low Poverty	High Poverty
Race				
White	68.7%	22.0%	70.0%	23.2%
Black	4.2%	27.0%	4.4%	29.0%
Hispanic	7.4%	40.2%	7.4%	36.8%
Asian	8.0%	2.3%	7.6%	2.2%
Other	11.7%	8.6%	10.6%	8.8%
Baseline score				
High	41.5%	11.4%	40.1%	11.8%
Mid	46.8%	47.8%	47.2%	48.2%
Low	11.7%	40.8%	12.7%	40.0%
% of 2020-21 Remote	14.7%	33.5%	13.4%	32.1%
% of 2020-21 Hybrid	53.0%	42.0%	52.4%	43.3%

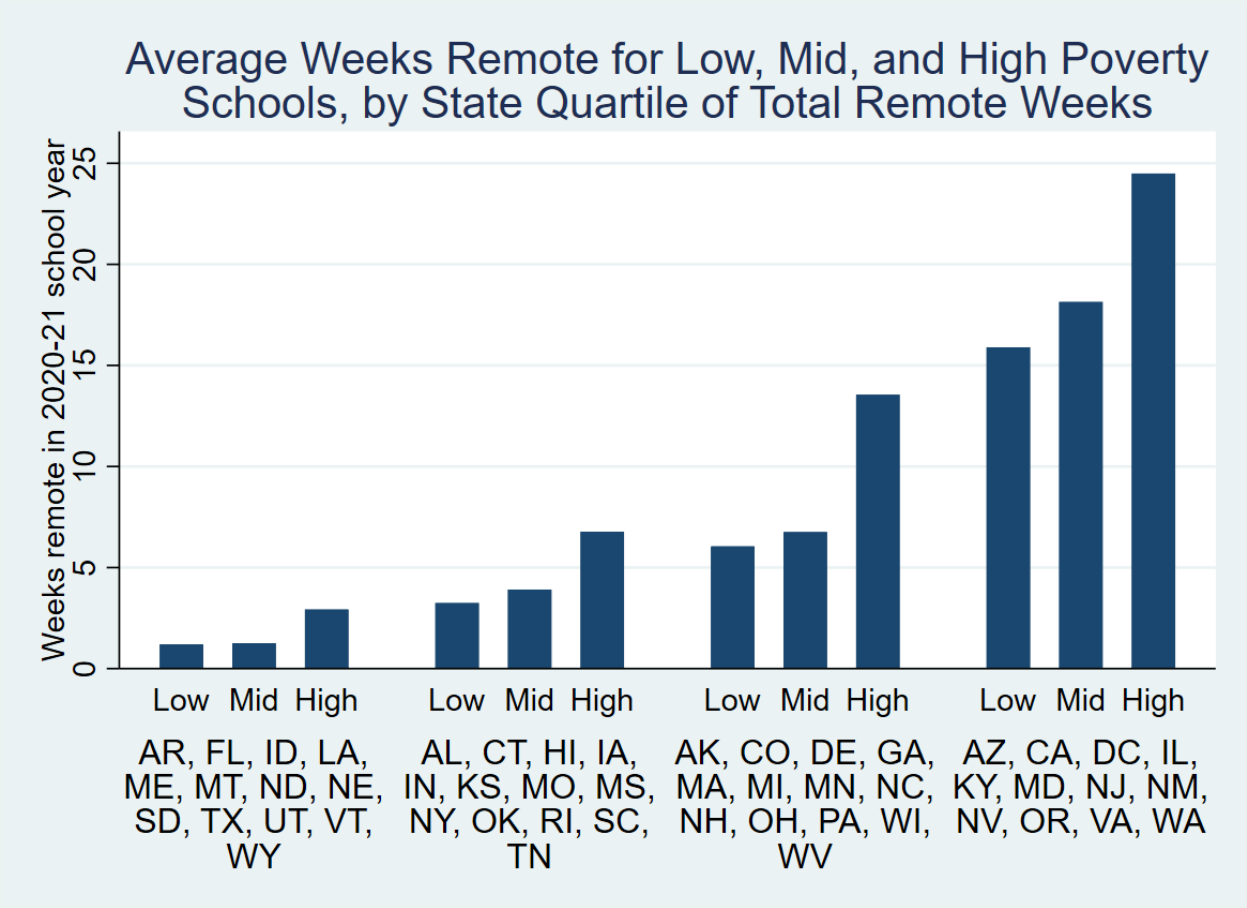
Note: These means are used for the decomposition calculation presented in Table 2 and Appendix B.

Appendix Table 7: Limiting Sample to Those with Scores in All Three Years: 2017, 2019 and 2021

	Math		Reading	
	17-19 Value-Add	19-21 Residual	17-19 Value-Add	19-21 Residual
Race (Reference: White)				
Black	-0.135	-0.049	-0.118	-0.027
	(0.008)	(0.007)	(0.008)	(0.007)
Hispanic	-0.017	-0.017	-0.024	-0.015
	(0.007)	(0.008)	(0.009)	(0.007)
Asian	0.200	0.019	0.142	0.011
	(0.009)	(0.010)	(0.009)	(0.011)
Other	-0.030	-0.024	-0.041	-0.002
	(0.007)	(0.008)	(0.008)	(0.006)
Baseline Score (Reference: Top Quartile)				
Middle Quartiles		-0.029		-0.009
		(0.004)		(0.003)
Bottom Quartile		-0.085		-0.043
		(0.004)		(0.006)
Linear Term of Baseline Score	0.755		0.738	
	(0.004)		(0.005)	
School Poverty (Reference: Low <25%)				
Middle (25%-75%)	-0.093	-0.017	-0.092	-0.012
	(0.012)	(0.013)	(0.014)	(0.012)
High (>75%)	-0.190	-0.003	-0.161	-0.026
	(0.022)	(0.025)	(0.021)	(0.018)
Remote Schooling				
% Remote in 2020-21	0.030	-0.201	0.040	-0.095
	(0.032)	(0.029)	(0.026)	(0.028)
Interactions:				
• Middle Poverty	-0.036	-0.121	-0.051	-0.040
	(0.029)	(0.031)	(0.026)	(0.026)
• High Poverty	-0.058	-0.202	-0.158	-0.077
	(0.037)	(0.042)	(0.042)	(0.037)
Hybrid Schooling				
% Hybrid in 2020-21	-0.015	-0.013	-0.022	0.030
	(0.016)	(0.020)	(0.017)	(0.017)
Interactions:				
• Middle Poverty	0.006	-0.084	0.011	-0.059
	(0.017)	(0.021)	(0.020)	(0.018)
• High Poverty	0.069	-0.152	0.048	-0.120
	(0.038)	(0.037)	(0.039)	(0.029)
Constant	0.120	-0.096	0.094	-0.037
	(0.013)	(0.012)	(0.014)	(0.010)
Fixed Effects?	No	No	No	No

Notes: The 2017-19 growth parameters were re-estimated using only students with a fall 2017, fall 2019, and fall 2021 test for a given subject, then these parameters were used to estimate the 19-21 residual regression on the full analysis sample. Because a fall 2021 test is required for students in the 2017-19 regression and only grade 1-8 testing data was available, only students who were in grades 3-6 in the latter term were included. Bootstrapped standard errors were estimated by resampling at the district level and re-estimating both equations (1) and (2) 1000 times.

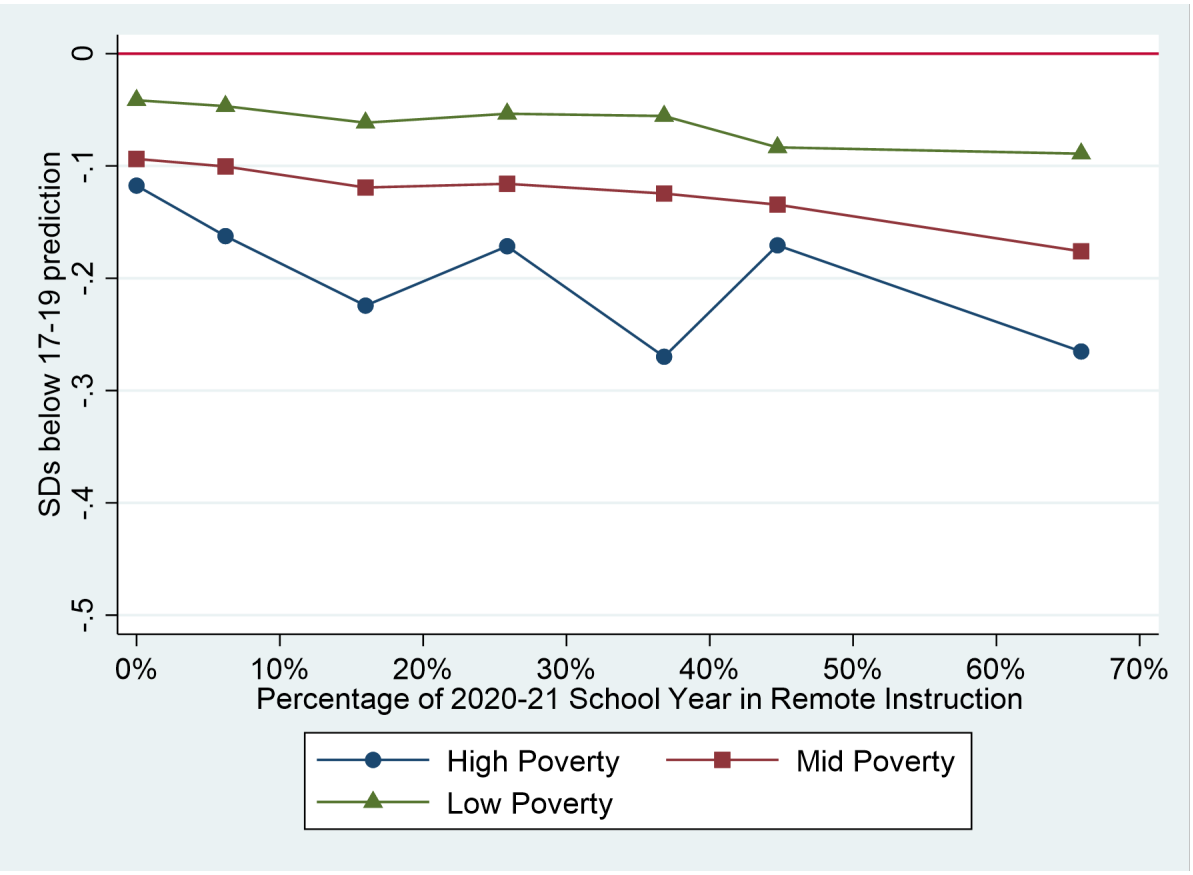
Appendix Figure 1. Differences in Remote Instruction by School Poverty Status and State



Note: Weeks of remote instruction are derived from American Enterprise Institute's Return to Learn Tracker. Data on school poverty come from information on the percent of students eligible for free or reduced price lunch (FRPL) in the Common Core Data from 2019-20, or the percentage of students directly certified in the National School Lunch Program if a state did not provide a count of FRPL students. Low poverty schools had fewer than 25 percent of students receiving federal Free or Reduced Price Lunch while high poverty schools had more than 75 percent of students receiving the federal lunch programs.

Appendix Figure 2.

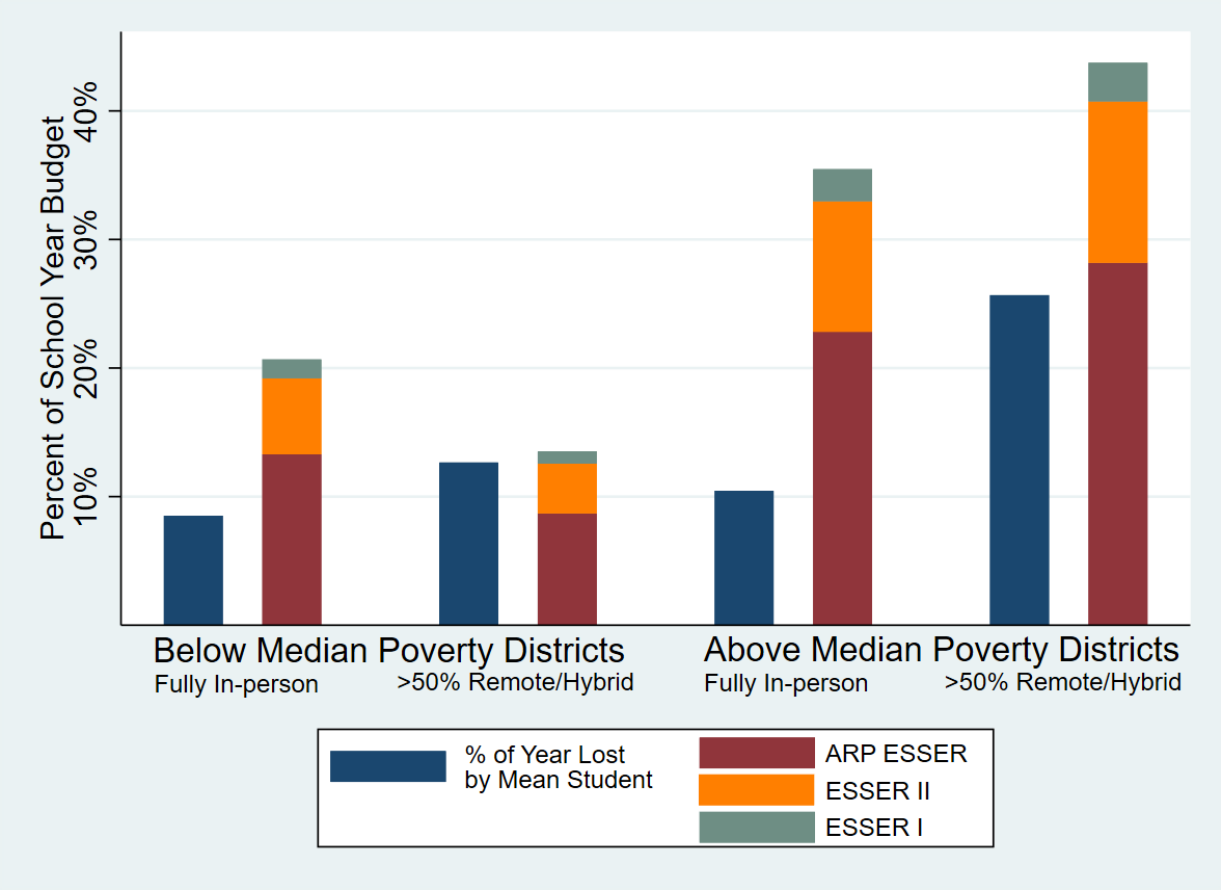
Pandemic Achievement Effects by Remote Schooling and School Poverty, Reading



Note: The vertical axis represents the difference between mean fall 2021 achievement and expected achievement based on pre-pandemic growth model estimates. The horizontal axis is the percentage of the 2020-21 school year that a school was in remote instruction. Given the small number of districts that were remote all year, the top category of percent remote combines those who were remote between 50 and 100 percent of the year. Low poverty schools had fewer than 25 percent of students receiving federal Free or Reduced Price Lunch while high poverty schools had more than 75 percent of students receiving the federal lunch programs.

Appendix Figure 3.

Pandemic Achievement Losses and Federal Aid as a Share of Annual Spending, Reading



Note: Achievement effects were converted into weeks of instruction using NWEA growth norms and divided by a 40 week school year (to reflect the fact that salaries and operational expenses are paid by calendar weeks, not the number of instructional weeks in a school year, which is typically 36 weeks). Federal aid is reported relative to the district's annual budget for K-12 schooling, minus capital expenditures. High poverty districts are the half of districts with the highest percent of students receiving Free or Reduced Price Lunch (and low poverty districts are the bottom half). Districts are considered "fully in-person" if the AEI reports no remote or hybrid instruction in the district during the 2020-21 school year.