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Abstract

The COVID-19 pandemic caused widespread disruptions to education, with school closures affecting over one billion children. These closures, aimed at reducing virus transmission, resulted in significant learning losses, particularly in mathematics and science. Using United States data from TIMSS, this study analyzes the impact of school closure on learning outcomes. The losses amount to 0.36 SD for mathematics and 0.16 SD for science. The declines are similar across grades. The average decline in mathematics performance among U.S. students is substantially greater than the global average. n science, the decline observed among U.S. students does not significantly differ from the global trend. Girls experienced greater deviations from long-term trends than boys across both subjects and grade levels, reversing long term trends that once favored girls. Robustness checks confirm that pandemic-related school closures caused the decline in mathematics, while the downturn in science had already begun before COVID-19.

Keywords: Pandemics, human capital, returns to education, labor markets, COVID-19

JEL Classification: E24, J11, J17, J31

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1 Introduction

During the COVID-19 crisis, one billion children missed one year of schooling, and of these children 700 million missed a total of 1.5 years of education. Many countries struggled to adapt to widespread school closures. The United States experienced some of the longest school closures globally. Compared to the global situation, the United States had one of the longest school closures. Schools were either closed or partially closed for around 667 days over the two-year period from January 2020 to December 2021, inclusive of typical school and summer breaks (Jack and Oster 2023). This learning crisis is not unique to low-income countries; it has also significantly impacted high-income nations, as Angrist et al. (2021) have shown, with widespread implications for students' educational outcomes globally.

Reviews of national and international studies show large learning losses, with estimates ranging from one-third to half a year's worth of learning (see Betthäuser et al. 2023; Crato and Patrinos 2025; Goldhaber et al. 2023; Jack et al. 2023; Jakubowski et al. 2023; Kennedy and Strietholt 2023; Jakubowski et al. 2025). These learning losses could translate to earnings losses and could cost this generation of students trillions of dollars (Psacharopoulos et al. 2021; Hanushek and Strauss 2025).

This study examines learning loss in the United States using TIMSS data released this year, focusing on mathematics and science achievement for grade 4 and 8 students, building on Gajderowicz et al. (2024). For the rest of the world, we found an average decline of 0.11 standard deviations (SD) in student achievement. The effects on low performers, girls, and linguistic minorities show effect sizes up to 0.22 SD.

For the United States, we find larger impacts. There are significant declines in performance compared to the expected values based on the long-term achievement trends for countries. For the United States, the effect sizes *above the international average* were 0.36 SD for mathematics and 0.16 SD for science. The declines in the USA are similar for both grades. An average decline for the USA students in mathematics is significantly larger than the global average. In science, the decline in the USA is statistically similar to the global decline. Girls experienced greater deviations from long-term trends than boys across both subjects and grade levels, reversing long term trends that once favored girls. In mathematics, girls lost around 0.44 SD, while boys lost 0.32 SD. In science, girls lost 0.20 SD while boys lost 0.11 SD. The learning loss estimate for students speaking a different language at home compared to the test language in mathematics is around 0.46 SD and in science 0.24 SD. Across the achievement distribution, learning losses are greater among the lowest-achieving students, with girls experiencing a decline about 10 points larger than boys across the achievement spectrum, and the highest-achieving students, particularly boys, showing minimal losses. Robustness checks confirm that in mathematics only the 2023 data showed a significant departure from the linear trend, while in science, both 2023 and 2019 indicated significant declines, suggesting that in math the pandemic school-closures were responsible for the decline, while in science the downturn had already started before COVID-19.

2 Data and Methods

We use data for the United States and other participating countries from the Trends in International Mathematics and Science Study (TIMSS), an international large-scale, repeated cross-sectional study that randomly samples fourth- and eighth-grade students to assess their achievement in mathematics and science. The curriculum-based assessments measure the knowledge students have accumulated over four and eight years of schooling, respectively. Conducted in four-year cycles, the 2023 cycle marks the first administration following the onset of the COVID-19 pandemic. Drawing on data from six cycles spanning 20 years, starting from 2003, this study examines long-term trends in student performance, allowing us to evaluate whether the 2023 results diverge from pre-pandemic patterns.

TIMSS not only captures student achievement, but also contextual information and characteristics of students through background questionnaires. We use this information as control variables to explain differences in achievement scores while also capturing changes to country demographics or samples over time. Specifically, we use four pieces of information that were consistently captured across all cycles of TIMSS from the student background questionnaire: student age, gender, grade, and how often the language of the test was spoken in the home.

To analyze changes following COVID-19, it is essential to consider long-term trends. We apply an empirical strategy commonly used to estimate international learning loss, which involves comparing the most recent 2023 results with historical linear trends in student achievement in mathematics and science across participating school systems (see Gajderowicz et al., 2024). We estimate a separate linear trend for each country and include country-level fixed effects to control for unobserved, time-invariant country characteristics. In estimating the departure from the long-term achievement trend in the United States and comparing it with other countries, we omit the fixed effect for the USA. This means that U.S. students serve as the baseline, while an interaction term is introduced between a dummy variable (K) representing all non-U.S. countries and an indicator for 2023 data (D_{2023}). The regression model is as follows:

$$Y_{ijk} = \Sigma_{k=2}^{n}\alpha_k + \Sigma_{k=2}^{n}\beta_k time + \gamma D_{2023} + \delta D_{2023}K + \theta X_{ijk} + \varepsilon_{ijk} \tag{1}$$

where Y_{ijk} represents the achievement of student i at school j in country k, with n being the number of countries in the sample being analyzed and with k=1 denoting data for the USA. The model is estimated on repeated cross-sections, with β_k capturing the slope of country-specific linear trends in student achievement across TIMSS cycles. D_{2023} is an indicator variable that is equal to one for the data collected during the 2023 cycle (after the onset of the pandemic) and is zero for all other cycles. With the data for the USA denoting a baseline, our parameter of interest is γ, capturing the deviation from the country-specific achievement trends in the USA population of 4^{th} and 8^{th}-grade students occurring after the onset of the pandemic, controlling for time-invariant country effects (α_k), country-specific time trends, and student background characteristics (X_{ijk}). When estimated with K denoting data for other countries, γ captures the deviation from the long-term trend for the USA, while δ captures the difference in this deviation for the other countries.

The model is estimated separately for mathematics and science, but jointly for grades 4 and 8 data. We also provide separate results by grade; however, these results rely on smaller samples and are more sensitive to sampling and measurement errors. The set of control variables includes student gender and age with 10 dummies representing age deciles within each grade to allow for non-linear age effects. It also includes language spoken at home, where students who always speak the test language serve as the baseline, with two dummies indicating those who sometimes or never speak the test language at home. To control for differences in country samples across time, we also control for the actual grade of students and for changes in the country-average age across time. In all regressions we rely on the plausible values method to estimate measurement errors, while the standard errors account for within-school correlation using the clustered sandwich estimator (Full details are available in Gajderowicz et al. 2024).

For the USA data, we test for differences in the impact of the pandemic by gender and home language. In the model (1), we add interaction terms between the indicator for gender (or language spoken at home) and between the linear trend and the 2023 departure dummy. Estimating the regressions with different baseline categories, we obtain separate results for boys and girls, and for students who always speak the same language as the language of the assessment at home and for those speaking it sometimes or never, and for the statistical difference between the two groups in the estimated learning loss. We also investigate the heterogeneity in the impact of school closures by achievement level using RIF unconditional quantile regressions comparing separately boys and girls. For these additional analyses, we focus on the sample of USA students only.

3 Findings

Learning loss estimates

Learning losses for the United States were greater than the international average. Table 1 presents the estimated deviations from long-term trends by subject. Overall, the models indicate significant declines in performance compared to the expected values based on the long-term achievement trends for countries. For the USA, achievement data collected since 1999 showed a positive trend, with an increase of around 4 points per year in mathematics and around 2 points per year in science. For the other countries, the trends were mixed, with some showing improvements or declines, but with the majority having similar performance over time. The 2023 results for the USA stand out significantly with a decline of 30.8 points in mathematics and 13.5 points in science.

To put the linear trend departures for the USA in a comparable perspective, we standardize them by the within-USA standard deviation (SD) for each subject (SD_{math}=85.5, $SD_{science}$=87.0). For the United States, the effect sizes *above the international average* were 0.36 SD for mathematics and 0.16 SD for science. The declines in the USA are similar for both grades (see Annex Table A3 for detailed results by grade). An average decline for the USA students in mathematics is significantly larger than the global average (Gajderowicz et al. 2024). In science, the decline in the USA is statistically similar to the global decline.

Table 1: Departure from the Linear Trend

	Mathematics	Science
The departure from the linear trend for USA students	-30.8***	-13.5***
	(3.8)	(3.6)
The difference in the departure from the linear trend between the USA and the other countries	22.5***	4.6
	(3.9)	(3.7)
USA-specific time trend in achievement	4.2***	2.1**
	(0.7)	(0.7)
Country fixed effects	Yes	Yes
Country-specific time trends	Yes	Yes
4^{th} grade and 8^{th} grade fixed effects	Yes	Yes
Grade-specific effects of age, gender, language spoken, and differences in the actual grade	Yes	Yes
N of students	2,824,034	2,823,098
N of countries/education systems	87	87

Note: Clustered standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001.

Learning loss and school closure effects by student background

The deviations from long-term trends differ by gender and home language as reported in Table 2. When examining differences by sex, we find that girls experienced greater deviations from long-term trends than boys across both subjects and grade levels. In mathematics, girls lost around 0.44 SD, while boys lost 0.32 SD. In science, girls lost 0.20 SD while boys 0.11 SD. Worth noting is that before the pandemic girls experienced a more positive trend in mathematics achievement (4.2 points per year compared to 3.5 points per year for boys). In science, only the scores for girls were improving before the pandemic (3.2 points per year compared to insignificant trend for boys).

Students who did not speak the test language most often at home experienced greater deviations from the long-term trends than those who did. Linguistic minorities suffered disproportionately. The learning loss estimate for students speaking the test language at home is similar to the main sample (around 0.37 SD in mathematics and 0.15 SD in science), but for students speaking in a different language, the learning loss in mathematics is around 0.46 SD and in science 0.24 SD.

Table 2: Departure from Linear Trend for the USA by Sex and Language

	Mathematics	Science
The departure for girls	-37.8***	-17.7***
	(3.9)	(3.8)
The departure for boys	-27.3***	-9.7*
	(4.3)	(4.1)
The difference in the departure (boys compared to girls)	10.4***	7.9**
	(2.5)	(2.7)
The departure for students speaking at home in the same language as the language of the test	-31.8***	-13.2***
	(4.0)	(3.8)
The departure for students speaking at home in a different language	-39.5***	-20.6***
	(5.9)	(5.5)
Difference in departure (students speaking different language at home compared to speaking same)	-7.7	-7.4
	(5.2)	(4.7)

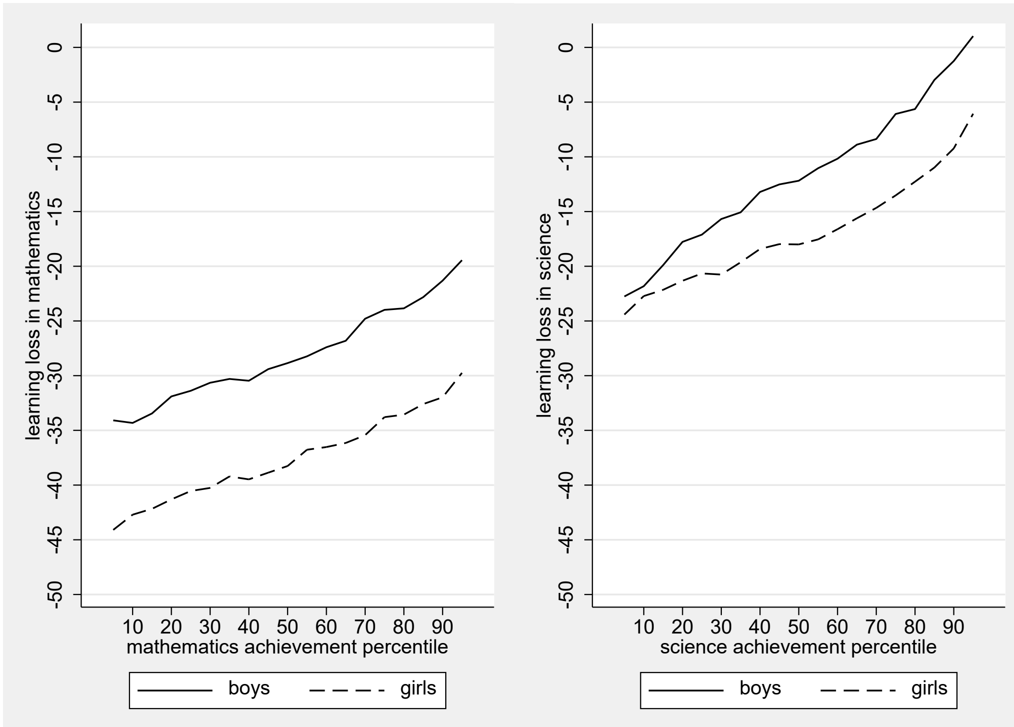
Note: Regression specifications as in Table 1. Clustered standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001.

Overall, the findings demonstrate significant deviations from long-term achievement trends in both mathematics and science in the 2023 cycle, with variations by sex and home language. Additionally, girls faced larger trend departures than boys across both subjects. The study also highlights that students who did not speak the test language at home experienced greater deviations from long-term achievement trends.

Learning loss by achievement level and gender

For the quantile estimates, we used RIF regressions on unconditional quantiles of achievement only for the United States data (Figure 1). We provide separate estimates for boys and girls at different achievement levels. In both subjects, learning losses are larger among the lowest achieving students. In mathematics, the difference between students at the bottom of the achievement distribution (5^{th} percentile to the left of each pane) and those at the top (95^{th} percentile to the right of each pane) is around 15 points or close to 0.2 SD. The differences between boys and girls are similar across the achievement spectrum, with girls experiencing a decline larger by around 10 points. In science, the gap between the bottom and top of the distribution is around 20 points, which is above 0.2 SD. The highest achieving boys did not experience a decline, while among the highest achieving girls the decline is also relatively close to zero. Among the lowest achieving students, the learning loss is similar for boys and girls and larger than 20 points.

Figure 1: Learning Loss by Achievement Decile

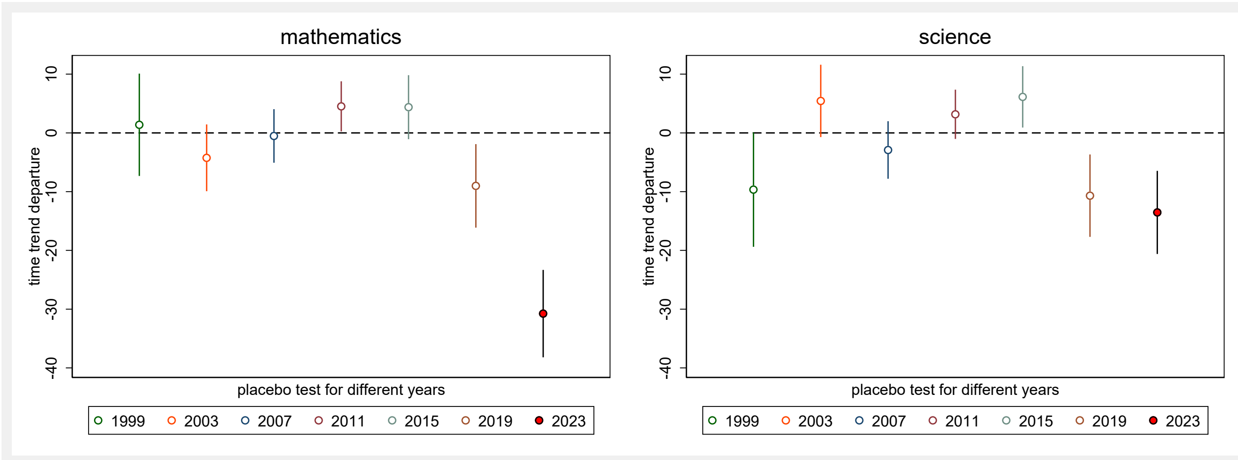


Source: Exact results with statistical tests are in the annex table.

Robustness checks

To ensure the results are robust we perform several checks. First, we conduct placebo tests to check if, assuming the same model, we detect a significant departure from the linear trend only in 2023. We run the same regression model (1) for mathematics and science but introducing a placebo effect in different years from 1999 to 2019, testing for significant departures from the linear trend for different TIMSS rounds. Figure 2 shows the results separately for each subject. In mathematics, the results indicate a significant departure from the linear time trend in 2023 only. In science, the 2023 departure is the most significant, but the departure in 2019 is also significantly below zero while 1999 also stands out but with large confidence interval overlapping with zero. In general, the placebo tests for mathematics suggest the 2023 departure from the linear trend is uniquely large compared to results collected since 1999, but in science the results in 2019 were also lower than before so the tests cannot exclude other explanations for the downwards trend in recent years.

Figure 2: Placebo tests



Second, we estimated the regression model (1) but with different regression and sample specifications: (a) taking USA data only, (b) with country fixed effects interacting with 2023 departure, (c) without any control variables, and (d) with population weights instead of the senate weights used for the main specification, which equalized each country's contribution to the final estimate. Table A1 in the Annex shows the results were almost identical across these specifications.

Finally, we estimate the same models as in the main specification but using shorter time spans. The results available in the Annex Table A2 show that considering shorter time trends in mathematics does not alter the main conclusions. For science, the time trend departure estimates become insignificant for the comparisons involving more recent years only.

4 Conclusion

The findings emphasize the critical need for targeted recovery strategies in the United States to mitigate the learning losses caused by the COVID-19 pandemic. Policies must focus on restoring lost educational content and providing tailored support for the most vulnerable groups, such as low-performing students, girls, linguistic minorities, and those facing socioeconomic disadvantages. While mathematics saw a distinct decline attributed to the pandemic, science losses were part of a broader trend that began earlier, underscoring the complexity of educational challenges that existed even before COVID-19.

Efforts to address these gaps should prioritize interventions that consider the varying needs across gender, home language, and achievement levels. The magnitude of learning loss in the U.S., particularly in mathematics, significantly exceeds the global average, illustrating that the learning crisis is not confined to low-income countries but also impacts high-income nations like the United States. Comprehensive, inclusive recovery plans will be necessary to prevent long-term consequences on students' future earnings and national economic performance.

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Annex: Robustness Checks and Results by Grade

Table A1. Regression specification tests: The departure from the linear trend for USA students

Main Specification	USA data only	Fixed Effects	Without controls	Population weight
		Mathematics		
-30.8***	-32.5***	-30.8***	-32.6***	-30.6***
(3.8)	(3.9)	(3.8)	(3.9)	(3.8)
		Science		
-13.5***	-13.7***	-13.3***	-15.3***	-13.3***
(3.6)	(3.7)	(3.6)	(3.8)	(3.6)

Table A2. Time span sample robustness checks

	1999-2023	2003-2023	2007-2023	2011-2023	2015-2023
			Mathematics		
The USA departure from the linear trend	-30.75***	-30.81***	-28.43***	-24.14***	-19.53**
	(3.79)	(3.90)	(4.21)	(4.80)	(6.51)
The difference between USA and other countries	22.51***	19.76***	15.53***	12.60**	11.78
	(3.86)	(3.97)	(4.29)	(4.88)	(6.62)
USA-specific time trend in achievement	4.16***	4.26***	3.10**	0.3	-3.06
	(0.66)	(0.75)	(1.03)	(1.61)	(3.51)
N of students	2,824,034	2,684,613	2,384,157	2,060,664	1,588,821
			Science		
The USA departure from the linear trend	-13.54***	-11.11**	-12.02**	-6.83	0.73
	(3.61)	(3.71)	(4.03)	(4.60)	(6.24)
The difference between USA and other countries	4.62	0.81	0.48	-4.06	-9.7
	(3.68)	(3.78)	(4.10)	(4.68)	(6.33)
USA-specific time trend in achievement	2.14**	1.24	1.74	-1.54	-7.09*
	(0.68)	(0.76)	(1.05)	(1.58)	(3.37)
N of students	2,823,098	2,683,677	2,383,221	2,060,664	1,588,821

Note: Clustered standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001.

Table A3: Departure from linear trend

	Grade 4		Grade 8	
	Mathematics	Science	Mathematics	Science
The USA departure from linear trend	-29.3***	-12.3**	-32.3***	-13.6*
	(4.6)	(4.4)	(5.9)	(5.5)
The difference between the USA and other countries	20.9***	7.9	21.9***	0.8
	(4.6)	(4.5)	(6.1)	(5.6)
USA-specific time trend in achievement	4.9***	1.9*	3.2***	1.4
	(0.9)	(0.9)	(0.9)	(0.9)
N of students	1,350,336	1,350,336	1,473,698	1,472,762
N countries	78	78	74	74

Note: Clustered standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001.