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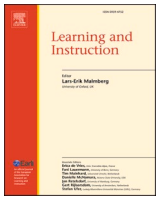

# Short- and long-term effects of COVID-related kindergarten and school closures on first- to eighth-grade students' school readiness skills and mathematics, reading and science learning

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ABSTRACT

Remote learning during the COVID pandemic has led to short- and long-term consequences for students' learning. So far, data on learning loss in early schooling have been limited. In this paper, we evaluate the effect of remote learning on 1st graders' school readiness skills and 2nd–8th graders' performance in mathematics, reading and science using rich data collected in Hungary before and during the pandemic (n ≈ 55,000). The results show that kindergarten children and 1st–4th-grade students were significantly negatively affected by COVID restrictions compared to their older peers. This difference was extremely large in schools with a high share of disadvantaged students. More specifically, 1st–4th-grade low-SES students made little or no progress while learning from home.

From spring 2020, the COVID pandemic caused serious disruptions to our everyday lives, including school education and kindergarten development. It changed learning and instruction, and the speed of development. In the last two years, due to health and safety issues, most governments have decided to close schools several times, as this has proved to be the most effective intervention against the spread of the virus. However, many education researchers have raised concerns about the future effects of these measures on the quality of learning. A number of countries introduced remote learning with varying degrees of efficacy, thus mitigating the negative effect of school closures. The restrictions not only affected the knowledge and skills of students already in school, but also those of children in kindergarten who did not receive the necessary instruction in school readiness, which is essential for a successful start of school. Educational inequalities have further exacerbated earlier existing differences (Dorn et al., 2020), as families have been more strongly involved in the education of their children (Bubb & Jones, 2020). As a result, children from less educated and poor families (Engzell et al., 2021) and younger children (Tomasik et al., 2021) in need of instruction in school readiness were more affected by the pandemic-related school closures.

The present study is the first to quantify both students' short-term and cumulative learning loss due to school closures and remote learning from kindergarten level up to the end of primary school (Grade 8) from a seven-year longitudinal perspective using data retrieved in 2015 and between 2018 and 2021. The research provides empirical evidence by investigating: (1) 1st graders' learning loss due to the lack of kindergarten education in the areas of reasoning skills and precursors to counting, computing and reading; and (2) 2nd–8th-grade students' learning loss in the three main domains of education, mathematics, reading and science, (a) in the autumn term of the 2020–21 academic year due to the changed learning and teaching environment because of a three-month school closure and remote learning (thus leading to short-term learning loss) and (b) during the autumn term of the 2021–22 academic year as a result of cumulative restrictions for two academic years (thus leading to long-term learning loss). Results demonstrate the evidence-based impact on students' achievement of pandemic-related short- and long-term school closures, and remote learning, including the changed learning and teaching environment, and non-traditional instruction.

## 1. Theoretical background

### 1.1. Prerequisites for learning success

Knowledge and learning are key factors in individual well-being, socio-economic development and international competitiveness.

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Prerequisites for the adequate processing of the learning material and the application of the knowledge acquired are sound reading comprehension, disciplined thinking and a well-grounded system of scientific concepts. First, mathematics, which offers disciplined thinking, is an integral part of our daily lives, and its development is strongly related to the development of reasoning skills (Molnár & Csapó, 2019). Its precursor skills are indispensable to success in school. Second, reading comprehension is an essential tool for learning and for managing life (Karst et al., 2022). Third, one of the main aims of teaching science is to help us understand the world around us. Continuous monitoring of students' performance in these three areas, signalling learning gaps and compensating for them are prerequisites for quality education and lifelong learning. Since the knowledge acquired during a child's education is mostly determined by family background (social, economic and cultural status) and the quality of schooling, any changes in these indices lead to a serious change in the level of students' knowledge and skills. The school closures might therefore have had differential effects on different groups of students. In addition, given the rigidity of the school curriculum and school instruction, which cannot adapt quickly to the knowledge level of students with a large learning gap upon re-entry to school, we can assume much greater learning loss among low-SES children (Kaffenberger, 2021) and younger children. In the last two years, restrictions tied to the COVID pandemic have had a strong effect on two factors: (1) family life and (2) school education, learning and instruction.

### 1.2. Pandemic policy on kindergarten and primary education in Hungary

In Hungary, all educational institutions, including kindergartens and primary schools, closed on 16 March 2020 and re-opened after the summer holiday on 1 September 2020. During these three months (13 weeks) until the summer holiday, schools officially switched to remote learning, but most students, parents and teachers were unprepared. As in other European countries, the impending school closure was announced on a Friday and digital teaching was to be started the following Monday, generating great uncertainty for both families and schools. Kindergartens re-opened on 25 May 2020 (after a ten-week break).

During the next school year, there were numerous local school and kindergarten closures between September and March owing to the spread of COVID, which was followed by a mandatory government school lockdown, which lasted six weeks for kindergarten and lower primary students (in Grades 1–4) and nine weeks for upper primary students (in Grades 5–8). Summer holiday started on 16 June 2021, and the following school year began on 1 September 2021. Afterwards, no mandatory lockdown was proposed until the end of 2021. That is, in Hungary, between March 2020 and December 2021, kindergartners spent a minimum of 16 weeks at home (with no official remote learning), lower primary students experienced a minimum of 19 weeks of remote learning, and upper primary students had a minimum of 22 weeks of online learning.

### 1.3. The impact of school instruction on students' development during "normal" teaching times

Measuring academic progress is an important issue for data-informed decision-making. In educational research, the impact of any instruction and intervention is typically reported on an abstract scale, in units of standard deviation, that is, with Cohen's *d*. Great emphasis has been placed on translating this standardized effect of educational programmes into a more readily and interpretable metric, such as units of time. Hanushek et al. (2012) argued for the simplest translation and use for all grades and subjects using the same scaling factor per year: $d = 0.25$. Bloom et al. (2008) also used year-based growth factors, but they varied by grade and subject, assuming $d = 1.14$ and 1.52 for development in mathematics and reading, respectively, between kindergarten and Grade 1, which values were constantly dropping each year, resulting in an average growth of $d = 0.81$ and 0.64 in the lower primary grades (Grades 1–4) and an average growth of $d = 0.34$ and 0.27 in the upper primary grades (Grades 5–8) for mathematics and reading, respectively.

Aucejo and Romano (2016) and Gershenson et al. (2017) used another approach and reported the d value not for a year of school development, but for each school day. Aucejo and Romano (2016) likewise argued for heterogeneous effects and distinguished growth effects by grade and subject at the primary level, but, in contrast to Bloom, they argued for larger effects on both mathematics and reading in the higher grades. Their results also indicated that "lower ability students have a harder time making up missed work" (p. 82). Further, Gershenson et al. (2017) argued for approximately linearly changing effects between 0.006 and 0.008 for each school day, which are two to three times larger among 4th- and 5th-grade students than among kindergartners and 1st graders. According to their results, growth effects are stronger for mathematics than for reading achievement, thus confirming Hanushek and Rivkin's (2010) findings. Fitzpatrick et al. (2011) estimated similar values for each day spent at school ($0.005 < d < 0.007$). The generalisability of these results to school closures during the COVID pandemic is limited, as the educational situation is different. Remote learning was introduced to replace in-person teaching, but, in practice, no systematic remote learning was implemented, thus leading to more heterogeneity in learning trajectories (Tomasik et al., 2021).

### 1.4. Short-term effects of COVID school closures

In the last two years, a number of studies have focused on the different effects of COVID restrictions, including the short-term effects of school closures on primary and secondary students' achievement in mathematics and reading (see large-scale studies: Clark, Nong, Zhu, & Zhu, 2021; Engzell et al., 2021; Gore et al., 2021; Kuhfeld, Tarasawa, et al., 2020; Liu et al., 2021; Meeter, 2021; Tomasik et al., 2021; Zierer, 2021), indicating on average of 10% ($d = -0.1$) and 9% ($d = -0.09$) SD learning loss for mathematics and reading, respectively (for a systematic review, see Hammerstein et al., 2021). However, less attention has been paid to cumulative, long-term effects on children's development or the effects on that of kindergarten children in particular. As regards the short-term effects of school closures on 2020 achievement, there is also evidence that remote learning had an effect similar to that of the summer holiday, where there is clearly no teaching (Hammerstein et al., 2021). No large-scale empirical research has been published which monitors students' knowledge gap from kindergarten up to the end of primary school from a longitudinal perspective in each of the most important domains of education: mathematics, reading and science. We aim to fill this gap and analyse data collected nationwide over the last seven years via a computer-based diagnostic assessment system before and during the COVID pandemic using several control variables to increase the validity of the results and rule out incidental changes in the sample.

## 2. The present study

The present analyses build on key findings of previous research and test the effects of in-person vs. remote learning (or the lack of it) in an unselected sample controlled for a rich set of school characteristics to estimate the potential learning loss that has occurred and accumulated from the outset of the COVID pandemic. First, we expect that the lack of in-person teaching results in a slower learning progress and decline in students' knowledge and skills compared to earlier years. This effect should be larger for very young learners, who started school without reaching the proper level of school readiness due to lack of kindergarten instruction. The effect should also be greater for lower primary students, who had to learn how to read, write and count and were less able to learn on their own. Finally, the effect should likewise be greater for at-risk students, who come from disadvantaged socio-economic backgrounds. At the same time, we also expected higher achievement, as results from research on digital teaching argue for more effective

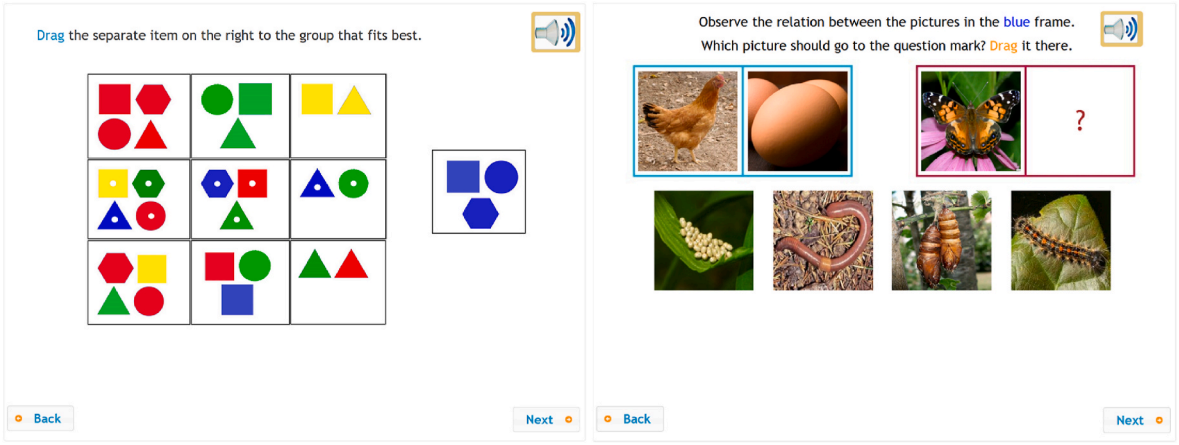


**Fig. 1.** Measuring the reasoning dimension of learning in the context of mathematics and science.

teaching and learning with technology potentially contributing to personalized education.

We aimed to answer four research questions. First (RQ1), what was the short- and long-term (cumulative) effect of the COVID-related kindergarten closures in autumn 2020 and autumn 2021 on pupils' school readiness? Second (RQ2), what was the short- and long-term (cumulative) effect of the COVID school closures in autumn 2020 and autumn 2021 on 2nd–8th-grade students' achievement in mathematics, reading and science? Third (RQ3), did the kindergarten closures have differential effects on specific groups of children? If so, which groups were more strongly affected by the COVID school closures? Fourth (RQ4), did the school closures have differential effects on specific groups of 2nd–8th-grade students in the three main domains of education? If so, which groups were more strongly affected?

## 3. Method

### 3.1. Sample

To detect changes in students' learning progress due to the school lockdowns and remote learning compared to normal teaching times, all the 1st–8th graders, users of the eDia system (Csapó & Molnár, 2019), who completed at least one assessment between 15 October and 15 November in 2015, 2018, 2019, 2020 and 2021, were included in the statistical analyses. We filtered the data before running the scaling procedures and analysing the results. We deleted answers provided by students on a given test from the dataset if they successfully completed fewer than ten items on the administered test, meaning their ability estimation would have been carried out with a large measurement error. As a result of this process, answers from a total of 130 students (0.16% of the total sample) were deleted (61 students in the pre-COVID years and 69 students in the COVID years), which has not modified the research results significantly. After we cleaned the dataset, the sample consisted of data collected from approximately 80,000 students ($N_{\_Grades2–7} = 61,431$; $N_{\_Grade1} = 16,726$; where N: number of students; see Appendix 1). Appendix 2 contains the number of schools and students in the sample for the pre-COVID and COVID years.

### 3.2. Instruments

Instruments administered to the 1st graders encompassed three domains: counting and basic numeracy skills (number of items: 57), precursors of reading skills (number of items: 30) and inductive reasoning (number of items: 25). Students in Grades 2–8 received mathematics, reading and science tests with items drawn from item banks constructed for diagnostic assessments to monitor their cognitive development in different dimensions of learning: the reasoning, application and disciplinary dimensions (Molnár & Csapó, 2019).

Tasks developed in the reasoning dimension of knowledge contain 'domain-specific reasoning skills' as well as general reasoning skills embedded in a different context and different content (Fig. 1). Tasks developed in the application dimension of knowledge monitor knowledge application in new contexts and require a deeper conceptual understanding of knowledge mastered at school (Fig. 2). Finally, tasks developed in the disciplinary dimension of knowledge build the most on curricular content (Fig. 3). The theoretical frameworks define the main

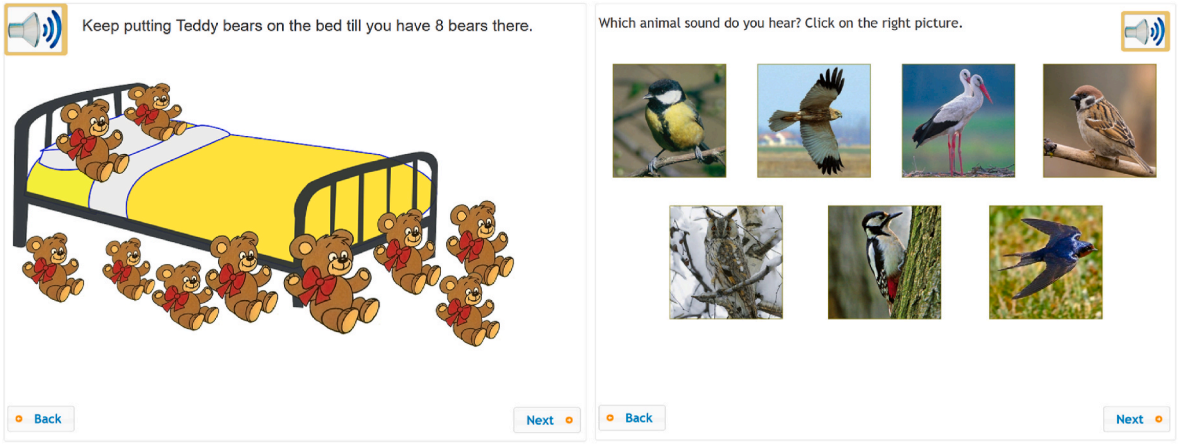


**Fig. 2.** Measuring the application dimension of learning in the context of mathematics and science.

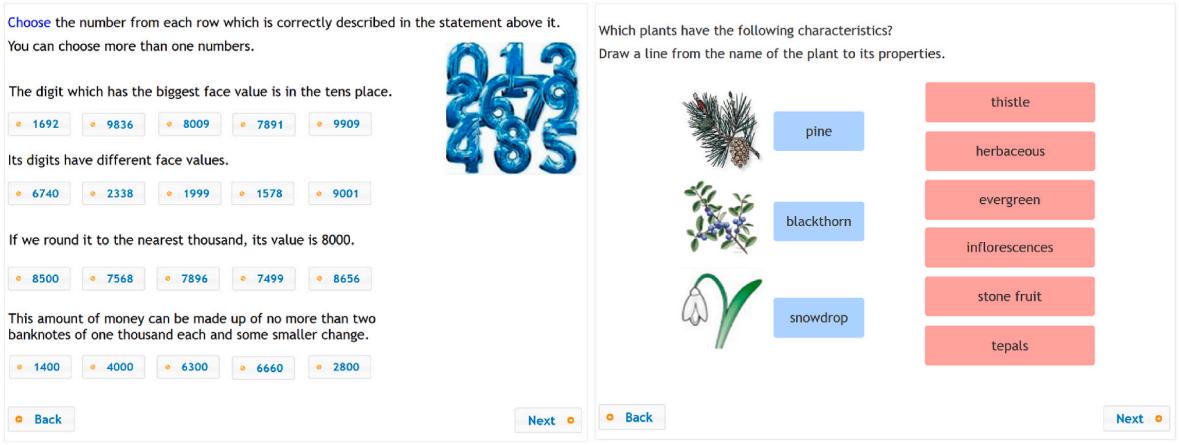


**Fig. 3.** Measuring the disciplinary dimension of learning in the context of mathematics and science.

**Table 1**
The number of items involved in the analyses and EAP (expected a posteriori) reliabilities.

| Grade | Mathematics | Reading | Science | Reliability M | Reliability R | Reliability S |
|---|---|---|---|---|---|---|
| 2 | 9324 | 8942 | 4655 | .924 | .917 | .884 |
| 3 | 12813 | 10875 | 6187 | .925 | .917 | .859 |
| 4 | 12991 | 12972 | 6493 | .914 | .901 | .831 |
| 5 | 13215 | 14076 | 7554 | .918 | .905 | .832 |
| 6 | 13209 | 12838 | 7754 | .917 | .895 | .823 |
| 7 | 11028 | 10140 | 7561 | .910 | .886 | .820 |
| 8 | 9337 | 7825 | 6177 | .926 | .891 | .824 |

milestones at a distance of two years, taking differences in students' cognitive development into account. As a consequence of the theoretical bases of the item banks and the rigidity of the school curriculum and school instruction, COVID pandemic-related remote learning has not changed the validity of the diagnostic assessments under investigation.

Table 1 consists of the number of items per domain and grade which have been used and scaled during the 2nd–8th-grade-level analyses. Each test administered to students in Grades 2–8 consisted of 50–55 items for the lower grades and 60–85 items for the higher grades. Anchor items were used between the tests administered in the same grade to scale the data.

The following steps were taken to improve the validity of the results. (1) When joining the system, the 1st–3rd-grade students completed a mouse and keyboard training session, which lasted one school lesson and in which they mastered the use of the relevant peripherals at least to the level required to complete the tasks. (2) In Grades 1–3, the students also received extra warm-up tasks before the cognitive test items to enhance keyboarding and mouse skills, and (3) beyond instruction provided in written form, they were also able to listen to the instructions with the help of a pre-recorded voiceover to avoid any potential reading difficulties. (4) After reading and/or listening to the instructions and completing the tasks, the students were asked to indicate their answer by using the mouse and/or keyboard or, in the case of touch screen tablets, by directly tapping, typing or dragging the task elements with their fingers.

The reliability indices of the tests and item banks were good, independent of grade and domain. In the case of the 1st graders, the *EAP* reliability of the tests varied between 0.84 and 0.91 and between 0.82 and 0.93 among the students in the upper grades.

### 3.3. Measures of the school context

To ensure that we were comparing performance among comparable groups of students, we used several control variables that measured school characteristics directly or indirectly. As the Hungarian education system is a selective one, it is important to control for differences in school composition and school quality. First, we measured school composition with the share of students with special educational needs and low SES in a particular grade at a particular school in the year of test administration based on school-level administrative data provided by the Education Authority. The share of low-SES students is measured by two indicators, disadvantaged students and highly disadvantaged students, both categories defined by law and recorded in school-level administrative data. These school characteristics are time- and grade-specific in order to account for changes in school composition over time. Second, we included the means for the mathematics and reading standardized test scores in Grade 6 and the share of students in the school with mothers with a university degree. These data come from a national assessment programme (NABC) that covers the full population of 6th graders (Sinka, 2010). The indicators were calculated for the 2017–2019 years combined, i.e. before the COVID years. These do not vary over time and are intended to capture cross-sectional differences across schools. Third, we also included school size (log scale), administrative rank of the municipality (indicator for villages as opposed to towns) and average income in the municipality based on school- and municipality-level administrative data from the Hungarian Statistical Office. Descriptive statistics for the variables are presented in Appendix 3.

### 3.4. Procedures

Each test lasted one school lesson, that is, 45 min. Test sessions were supervised by teachers, who received written instructions on the test administration in advance. All of the assessments were delivered via the eDia system (Csapó & Molnár, 2019). The eDia system is an integrated online assessment platform that supports all assessment processes from technology-based test administration and IRT-based data analyses to an easy-to-use and well-interpretable feedback module. In Grade 1, the students received fixed tests; that is, after entering the system, all of them received the same test items. In Grades 2–8, they were instructed

to choose the domain (mathematics, reading or science), and the online system randomly selected one grade-appropriate test for each student out of the 220 tests for the particular domain.

To learn to use the assessment platform, the students were provided with instructions at the very beginning of the test, and, in Grades 1–3, the were given five trial (warm-up) mouse and keyboard usage tasks with immediate feedback. These instructions covered the following: (1) a yellow bar at the top of the screen showed how far along they were on the test; (2) they clicked or tapped on the speaker icon to listen to the task instructions (in Grades 1–3); (3) they clicked on the "next" button to receive the next task; and (4) after completing the test, they received immediate feedback on their total and dimension-level achievement.

Ethical approval was not required for this study based on national and institutional guidelines. The coding system for the online platform masked students' identity. The results were only disclosed to the participating students (as immediate feedback) and their teachers. Because of the anonymity and no-stakes testing design of the assessment process, it was not required or possible to request and obtain written informed parental consent from the participants.

### 3.5. Data analyses

The Rasch model was used to scale the data in each grade and domain separately. Linear transformation of the logit metric was chosen, and the mean for the *WLE* estimates in each grade and domain was set to 500 with a standard deviation of 100. As a result of this scaling procedure, it was possible to observe any changes over the years within the same grade. *EAP* reliability was estimated to determine the measurement accuracy within the scope of item response theory, which is comparable to the reliability measure of Cronbach's α from classical test theory (Wess et al., 2021).

As schools are free to join the eDia system, the sample of participating schools is a self-selected one. Moreover, the sample of schools can change from year to year, resulting in changes in the average characteristics of the students. A major concern related to changes in the sample of schools over time is that we were observing achievement among students from different backgrounds or schools of varying educational quality before and during the pandemic. In order to account for these differences, we used linear regression models to estimate learning loss, while controlling for a rich set of school characteristics. The equation of the model is as follows:

$$Y_{ijkrt} = \beta_0 + \beta_1 D_t^{2021} + \beta_2 D^{2022}{}_t + \beta_3 X_i + \beta_4 S_{jrt} + \beta_5 M_k + \beta_6 G_r + e_{ijkrt}$$

where Y is the *WLE* estimate of student *i* at school *j* in municipality *k* in grade *r* and in year *t*. X, S and M represent vectors of student, school and municipality characteristics, respectively. G is a set of indicator variables for the grade, and parameter *e* is the error term. Key variables of interest are $D^{2021}$ and $D^{2022}$, indicators for achievement measured in autumn 2020 and autumn 2021. Coefficients $\beta_1$ and $\beta_2$ estimate the average learning loss relative to the pre-COVID years in the average school in the sample. The former indicates immediate learning loss after a few months of school closure, while the latter represents cumulative learning loss, comparing average student achievement in the second year of the pandemic to that in pre-COVID years.

Student-level controls include gender, age (relative to expected age in the grade) and the month of the test. School and municipality characteristics are direct measures and correlates of school composition and school quality.

Our school- and student-level control variables contain missing data. The share of missing observations varies between 0.07 and 4.5% for the school composition variables, while it is 15 and 28% for student age and gender, respectively. We used multiple imputation to fill missing values, employing iterative multivariate imputation with chained equations (MICE) (Raghunathan et al., 2001; Royston, 2004). We included all the variables of the analysis model in the imputation model and also added school-level means over all grades of grade-specific school composition variables. We created 20 imputations of missing values, fitted the model separately for the 20 datasets and combined the results to arrive at the final estimates for the coefficients and standard errors. To account for the fact that students in the same school are observed independently and error terms might be correlated within schools, we calculated standard errors clustered at the school level.

In order to test the robustness of our results, we also estimated regression models for the subset of schools observed both before and during the pandemic, including school fixed effects. This specification uses only within-school variation to estimate learning loss, so both observed and unobserved time-invariant school characteristics are controlled for (Maldonado & De Witte, 2022). The results were qualitatively identical.

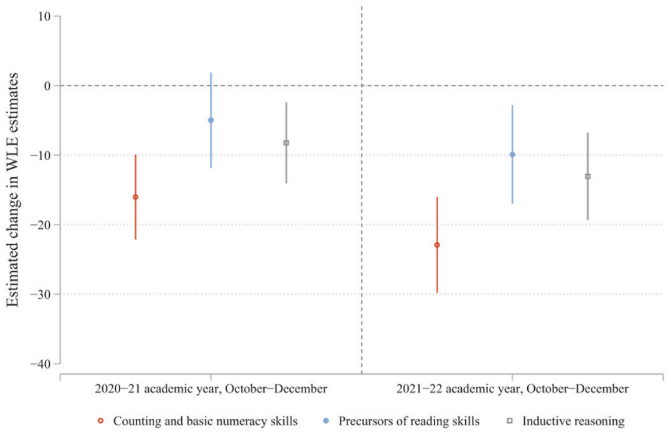


**Fig. 4.** Learning loss in school readiness skills (basic maths, reading and reasoning skills) with three months of kindergarten closures in the 2020–21 school year and cumulative knowledge loss among pupils starting school a year later compared to the pre-pandemic sample.
*Note.* Pre-pandemic sample: 2018 and 2019. Analyses are controlled for school characteristics and the effect of students' gender and age. Point estimates and 95% confidence interval. *Mean* = 500, *SD* = 100.0: No change can be detected.

## 4. Results

### 4.1. The effect of the COVID-related kindergarten closures on pupils' school readiness

We demonstrated changes in pupils' cognitive development as regards school readiness skills after the first wave of kindergarten lockdowns in 2020 (three months without explicit kindergarten instruction) and a year later in 2021 (a minimum of 16 weeks of kindergarten lockdowns; Fig. 4). See Appendix 4 for the full results of the regression models. The change in pupils' cognitive development from the lack of targeted kindergarten instruction was noticeable even after the first wave of kindergarten closures. The greatest learning loss (16 points, 16% of one standard deviation, $d = -0.16$) was detected for numeracy skills ($SD = 100$).

A year later, the cumulative impact of the kindergarten closures in numeracy and basic maths skills was a quarter of a standard deviation ($d = -0.23$; 23 points), which proved to be significantly larger ($F(1, 269) = 3.98$, $p = .046$) than the learning loss detected after the first three months of kindergarten closures. As regards the precursors of reading (ten points) and reasoning skills (twelve points), the learning loss did not increase significantly in the additional year (see Appendix 5).

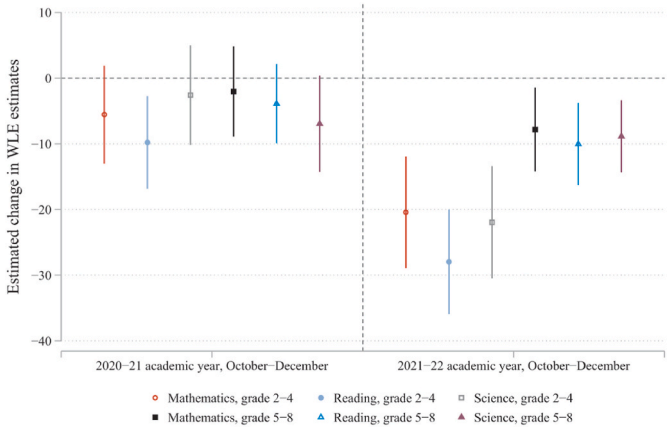


**Fig. 5.** Learning loss in mathematics, reading and science with three months of school closures and remote learning in autumn 2020 and cumulative learning loss among 2nd–8th-grade students a year later compared to the pre-pandemic years.
*Note.* Pre-pandemic sample: 2015, 2018 and 2019. Analyses are controlled for school characteristics and the effect of students' gender and age. Point estimates and 95% confidence interval.

### *4.2. The short- and long-term (cumulative) effect of the COVID school closures on 2nd–8th-grade students' achievement in mathematics, reading and science*

First, we found grade-level learning loss in mathematics, reading and science (see Appendix 6). Results indicated similar patterns in Grades 2–4 (ages 8–10) and Grades 5–8 (ages 11–14). Thus, to increase the validity of the results by decreasing measurement error using much larger samples in the analyses, we decided to introduce domain-level learning loss based on these two large groups of students: lower primary students (but not 1st graders) and upper primary students. See Appendix 4 for the full results of the regression models.

Second, we demonstrated the results of the group-level analyses and synthesized the learning loss of the lower (Grades 2–4) and upper primary (Grades 5–8) students in mathematics, reading and science (Fig. 5). The three-month-long quarantine and remote learning situation in spring 2020 also induced learning loss, which mostly affected lower primary students' mathematics and reading comprehension skills. After the first wave of remote learning, learning loss was between three and ten points (3–10% of one standard deviation, $d = -0.1$ to $-0.03$) at both of the primary levels. This proved to be the largest in reading comprehension among the lower primary students and the smallest for learning mathematics and reading in the upper primary grades.

A year later, tendencies changed immensely and learning loss among the lower primary students grew significantly [$F\ (1,\ 287) = 9.23$, $p = .000$ for mathematics, $F\ (1,\ 283) = 13.13$, $p = .000$ for reading and $F\ (1,\ 276) = 13.40$, $p = .000$ for science, see Appendix 5], almost by one-fifth of a standard deviation, resulting in an average 20–28 points (one-fourth of a standard deviation) of accumulated learning loss compared to the pre-pandemic samples. The upper primary students' learning loss proved to be significantly larger in reading than it was after the first three months of remote learning (see Appendix 5).

### *4.3. The effect of kindergarten closures on specific groups of children*

Fig. 6 shows that kindergarten closures and the lack of explicit instruction had different effects on students with different socio-economic backgrounds. There was no difference in learning loss for precursor skills for reading and inductive reasoning in the mean achievement of children in low-SES schools compared to their peers in high-SES schools after the first wave of the COVID pandemic in October 2020 as well as after one-and-a-half years. (Please note that this is not a matter of

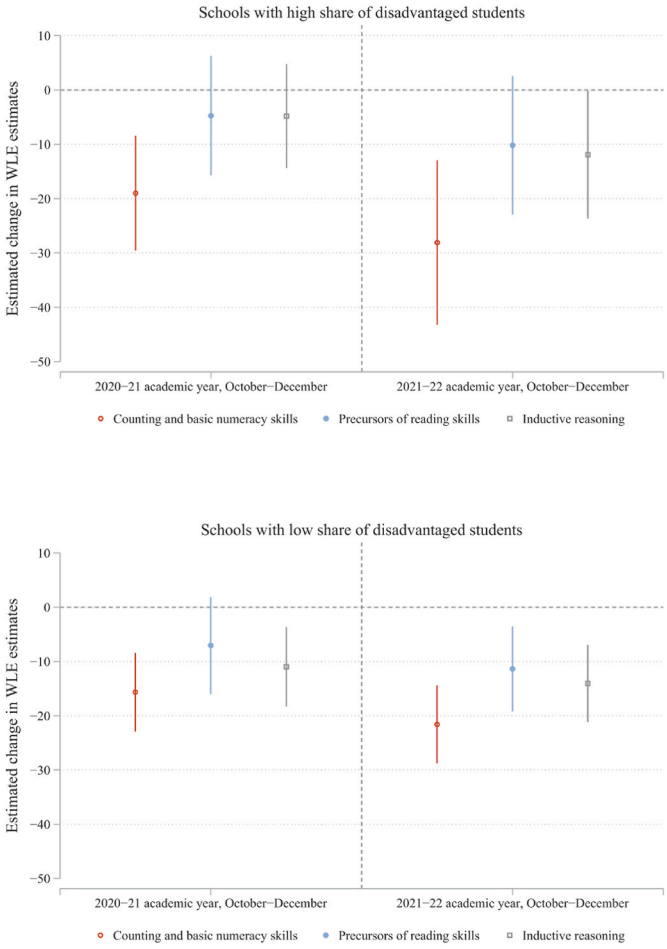


**Fig. 6.** Learning loss detected in students' school readiness skills in the 2020–21 and 2021–22 school years compared to those in the 2018–19 and 2019–20 school years in schools with high and low rates of low-SES students.
*Note.* Estimated coefficients of indicator variables representing COVID years, controlling for grade, school characteristics, and students' gender and age. Pre-COVID sample: 2018–19 and 2019–20 academic years. High (low) share of disadvantaged students: 10% and above (below 10%). Point estimates and 95% confidence intervals.

achievement differences between low- and mid- and high-SES students, but about their learning loss compared to the pre-pandemic years.) Cohen's $d$ varied between $-0.1$ and $-0.05$. The lack of explicit kindergarten-level instruction manifested the most among students in low-SES schools in terms of basic counting and numeracy skills, a level which proved to be a one-fifth standard deviation lower ($d = -0.2$) than before the COVID period. This pattern was both similar and different a year later. Basic maths skills still proved to be the most challenging domain, yielding the greatest learning gaps (29 points' lower achievement, $d = -0.3$) and the largest differences in students' cognitive development. The differences in learning loss detected in 2020 and 2021 proved to be non-significant (see Appendix 5). Generally, children in low-SES schools were more strongly affected than their peers at both a three-month and a one-and-a-half-year distance.

### *4.4. The effect of school closures on specific groups of 2nd–8th-grade students in the three main domains of education*

Now, we will compare 2nd–8th-grade students' learning loss based on SES using the grouping algorithm from RQ2. The average learning loss among students in low-SES schools proved to be greater. Lower primary students were generally more affected than those in the upper

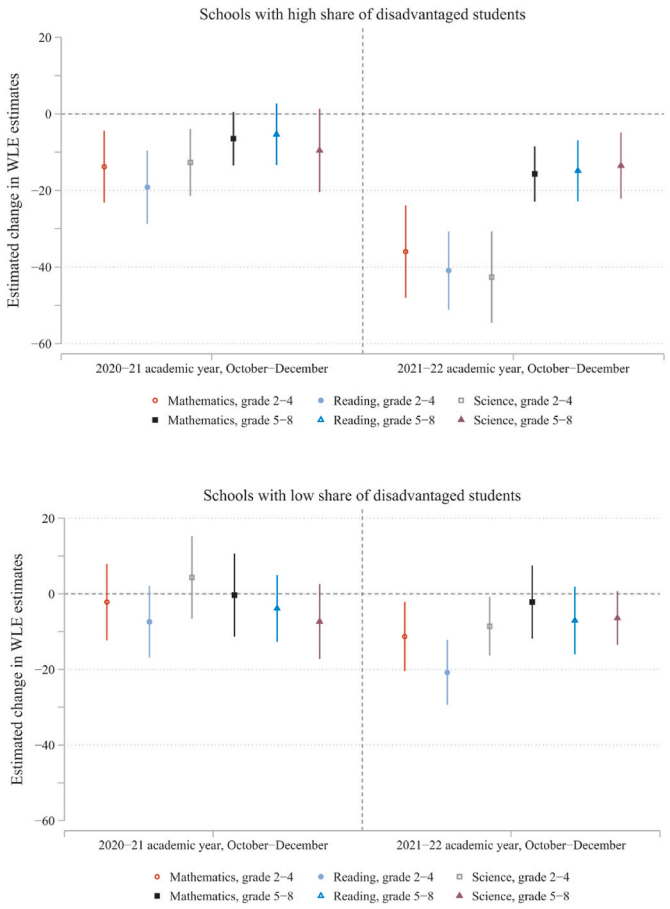


**Fig. 7.** Estimated learning loss in mathematics, reading comprehension and science among lower and upper primary students in schools with a lower and higher proportion of disadvantaged students in the autumn of the 2020–21 and 2021–22 school years.
*Note.* Estimated coefficients of indicator variables representing COVID years, controlling for grade, school characteristics, students' gender and age, and month of the test. Pre-COVID sample: 2015–16, 2018–19 and 2019–20 academic years. High (low) share of disadvantaged students: 10% and above (below 10%). Point estimates and 95% confidence intervals.

primary grades. This difference was about ten points on average after the first wave (three months) of remote learning, but increased significantly (see Appendix 5) to 25 points in mathematics, 20 points in reading and 33 points in science ($d$ = −0.25, −0.20 and −0.33, respectively) among lower graders and to 10 points on average ($d$ = −0.1) among upper graders at a distance of one school year. There are no low-SES upper primary students without significant growth in learning loss between 2020 and 2021 (see Fig. 7 and Appendix 5).

## 5. Discussion

This study shows that the COVID-related remote learning and kindergarten closures, the changed learning and teaching environment, and the changed instruction had a significant impact on kindergarten-aged and 1st–8th-grade children's cognitive development in the most important domains of kindergarten and school education. It provides important insights into the constantly increasing changes in learning loss in pupils' school readiness skills, expanding our knowledge about 1st graders knowledge and skills in 2020 and 2021 compared to the pre-pandemic years. It also shows changes in 2nd–8th graders' reading, mathematics and science knowledge due to the short-term and cumulative remote learning compared to earlier years and highlights groups of students who were more affected by the lack of in-person learning and instruction, who need extra help to catch up to avoid dropout. We used state-of-the art analyses on data collected before and during the pandemic in the same period of the year to quantify cognitive differences in students' development. Pre-pandemic achievement data (2015, 2018, 2019) were used as benchmark indicators in this study, and control variables measuring student and school characteristics directly or indirectly were included to assure full comparability of the samples.

### 5.1. *The COVID-related kindergarten closures had the greatest effect on pupils' basic counting and numeracy skills as regards school readiness skills (RQ1)*

We found both short- and long-term effects of kindergarten closures and the lack of explicit in-person instruction on pupils' school readiness skills. That is, students starting school in 2020 and 2021 were differently skilled on average than students in the pre-pandemic period. According to Bloom et al. (2008) – assuming a $d$ = 1.52 and 1.14 development for reading and mathematics, respectively, between kindergarten and Grade 1 – we can estimate an average development of $d$ = 0.008 for reading and an average development of $d$ = 0.006 for mathematics during a day spent in kindergarten. (Please note that kindergarten is available for 180 days per school year in Hungary.) This approximation also seems valid based on Gershenson et al. (2017) and Fitzpatrick et al.'s (2011) estimations. Based on Bloom et al. Gershenson et al. and Fitzpatrick et al.'s developmental index, after the first wave of kindergarten closures in 2020, the rate of loss was approximately equal to a length of 26 school days in basic counting and numeracy skills. (This amounts to five weeks. Please note that the length of the developmental time lost was ten weeks.) The learning loss was not immense for the precursor skills for reading and inductive reasoning, six and 13 school days, respectively – like the learning loss during a regular illness.

A year later, in 2021, students' numeracy skills were the most affected again by the lack of explicit in-person instruction. The learning loss among pupils starting school in 2021 proved even larger than it was in 2020; that is, learning loss increased further, resulting in almost one-fourth of an *SD* lower average achievement than in the pre-pandemic period. This is equal to 40 days (eight weeks) of learning loss (after at least 16 weeks of kindergarten closure), meaning that learning loss increased linearly in basic maths skills in proportion to the number of days spent outside kindergarten and it can be estimated to be equal to half as many days without explicit kindergarten instruction.

Similarly to the short-term effects, students' precursor skills for reading and their reasoning skills were not affected as strongly as their maths skills due to the long-term kindergarten closures and the lack of proper instruction from kindergarten teachers. On average, the cumulative effect is equal to two weeks of developmental time, which is not so immense. (Sometimes pupils miss kindergarten instruction for as much as two weeks during normal teaching times because of different illnesses.) One possible interpretation of this may be that the stimulation of inductive reasoning and precursor skills of reading are not pursued explicitly at kindergarten level as much as the development of basic counting and numeracy skills, thus also resulting in more spontaneous and basically slow development of inductive reasoning and precursor skills of reading in normal teaching time (Molnár et al., 2013). Another possible interpretation of this may be the domain-specific differences in the home learning environment. Segers et al. (2015) showed that parents engage more frequently in parent-child literacy activities than in parent-child numeracy activities and both aspects are related differently to children's literacy vs. numeracy skills. Similar evidence has been provided by Junge et al. (2021) regarding kindergartners early knowledge of science which may play a role in the development of inductive reasoning skills. To sum up, the results imply that the COVID-related kindergarten closures and the lack of explicit kindergarten instruction had the greatest effect on pupils' basic counting and numeracy skills as regards school readiness skills, thus suggesting teachers in Grade 1 need

to use different teaching material to compensate for the lack of school readiness skills.

### 5.2. Lower primary students were the most affected by the lack of in-person learning, and their learning loss increased linearly (RQ2)

The results indicated that the lower primary students were the most affected by the lack of in-person learning and instruction. Moreover, their learning loss accumulated and increased linearly in proportion to the amount of time spent in remote learning. The rate of learning loss over a three-month period of time (Cohen's $d = -0.1$ to $-0.04$; Cohen, 1988) was in line with earlier research results (see e.g. Hammerstein et al., 2021). According to Bloom et al. (2008), it was twelve days (about two to three weeks) in mathematics, 25 days (five weeks) in reading and ten days (two weeks) in science. The cumulative long-term effects proved to be significantly higher and corresponded to a learning loss of about nine weeks ($d = -0.2$, about one-fourth of a whole school year) in mathematics, 15–16 weeks in reading and 10–11 weeks (more than one-fourth of a whole school year) in science in the lower primary grades. (Please note that a whole school year consists of 181 working days in Hungary.)

The reason for this could be that lower primary students are less equipped with proper ICT infrastructure at home, they are not sufficiently skilled, self-regulated learners, they are not able to learn and process the curriculum on their own, and they have a greater need for the presence and constant feedback of their teachers, who have probably been insufficiently prepared to teach reading, writing and counting using a video conference system. In the absence of relevant methodological expertise, parents were less able to support their children in acquiring the knowledge that underlies their learning, a situation aggravated by the fact that the presence of a social environment plays a key role in children's socialization and learning. On a general level, upper primary students managed to follow online school instruction with greater success, and their short- and long-term learning loss proved to be much smaller than that of their peers in the lower primary grades.

### 5.3. COVID-related kindergarten closures have further widened educational inequalities between low- and mid- and high-SES students (RQ3)

As regards RQ1, we have learnt that kindergarten children's cognitive development was negatively affected by the three-month kindergarten closure after the first wave of the COVID pandemic. This learning loss increased and accumulated further among children starting school a year later, in 2021. Now, we went further and monitored this phenomenon from a socio-economic point of view and compared learning loss among students in low-SES schools, i.e. schools where the proportion of low-SES students is greater than ten per cent, with the developmental speed of their peers. (Because of the high selectivity of the Hungarian school system, we refer to the former group of students as low-SES, but please note that this does not mean that all of the students in that school fall within that category.)

As we expected and based on the literature on low-SES students (e.g. Bubb & Jones, 2020; Dorn et al., 2020; Engzell et al., 2021), COVID-related kindergarten closures have further widened educational inequalities and earlier existing differences between low- and mid- and high-SES students. More specifically, the cognitive development of children in low-SES schools was more strongly affected by the lack of explicit kindergarten instruction. The lack of it was most noticeable in students' basic counting and numeracy skills, which proved to be one-fifth of a standard deviation lower in 2020 and almost one-third of a *SD* lower in 2021 than before COVID. (These losses correspond to 46 school days of development. Please note that these children spent a minimum of 16 weeks at home without explicit kindergarten instruction until autumn 2021.) The development of low-SES students' precursor skills for reading and inductive reasoning was affected by kindergarten closures as much as that of their mid- and high-SES peers. That is, on a general level, most 5–6-year-old children need extra instruction, especially in basic numeracy and counting skills, to compensate for learning loss during the kindergarten closures.

### 5.4. The negative effect of COVID-related remote learning proved to be the largest among the lower primary low-SES students (RQ4)

As regards RQ1 and RQ2, we have learnt that younger children were more negatively affected by COVID restrictions than their older peers. The learning loss increased constantly and was significantly greater in autumn 2021 than a year earlier. This difference was largest among younger children. As regards RQ3, we found that the development of school readiness skills among low-SES students was far more affected by the lack of in-person kindergarten instruction than it was for their peers. Now, we went further and compared 2nd–8th-grade students' learning loss based on SES using the grouping algorithm from RQ2.

The negative effect of COVID-related remote learning was the largest among the lower primary low-SES students, and it increased constantly in proportion to the amount of time spent in remote learning. As a result of this phenomenon, we detected learning loss among students in low-SES schools in autumn 2021 equal to 78, 113 and 105 days (16, 23 and 21 weeks) in mathematics, reading and science, respectively. This equals or even exceeds the number of weeks (19 weeks) spent in government-mandated remote learning. This implies that remote learning has significantly exacerbated earlier existing differences, inequalities and learning gaps between low- and mid- and high-SES lower graders, which may have tragic and serious consequences for 1st–4th-grade low-SES students as regards dropout without targeted, methodologically well-planned compensation to overcome the accumulated learning loss. The learning loss among lower-grade low-SES students is as great as if they had had no teaching or as if they had had a summer break. Based on the detected tendencies, we assume that despite the fact of having mostly 'normal teaching time' from autumn 2021, this learning loss has accumulated further and produced even larger lags and learning gaps behind mid- and high-SES students. One possible interpretation of this can be that teachers in low- and high-SES schools taught online with different effectiveness, or it may perhaps be more likely, because, in the case of low-SES students, parents could not compensate for the missed school education as effectively as was the case with high-SES students.

## 6. Limitations

The limitations of this study include the sampling procedure. However, the analyses are based on very large data and samples collected nationwide. The results have been controlled for a number of student- and school-related factors, thus ensuring that there was no bias between the pre-pandemic and pandemic samples but not guaranteeing that the same results would be obtained for a representative sample. Another limitation of the study is that we have no knowledge of the way remote learning was put in practice. In interpreting the results, we have used different international data on the amount of students' development within a school year, an indicator that is strongly influenced by the degree of the differences between students within a single grade.

## 7. Conclusions

The results of the current study quantify students' short-term and cumulative long-term learning loss in the three main domains of education and in students' school readiness skills due to the kindergarten and school closures and remote learning during the COVID pandemic. The findings cover a wide age range, from kindergarten up to the end of primary education, with a seven-year perspective using data retrieved in autumn 2015, 2018 and 2019 (pre-COVID) and in 2020 and 2021. As for the educational implications, the results provide empirical evidence for

the amount and type of learning loss and highlight groups of students whose cognitive development was the most affected by the lack of explicit in-person teaching, learning and instruction. Educational researchers offer a number of recommendations on how to compensate for accumulated learning loss (Schult et al., 2022; Kuhfeld, Soland, et al., 2020). Borman (2020) proposes school-based summer programmes to increase year-round learning opportunities, Meeter (2021) recommends introducing formative online assessment to engage students and increase performance, and Muijs and Reynolds (2017) highlights the importance of motivating students with high-quality learning tasks and effective feedback. On a general level, learning and instruction need to be adapted to new learning needs regardless of students' situation at home. The present results offer valuable input for the design of appropriate learning tasks and the teaching of students to avoid dropout.

## Ethics statement

Ethical approval was not required for this study in accordance with the national and institutional guidelines. The assessments which provided data for this study were integrated parts of the educational processes of the participating schools. The coding system for the online platform masked students' identity; the data cannot be connected to the students. The results from the no-stakes diagnostic assessments were disclosed only to the participating students (as immediate feedback) and to their teachers. Because of the anonymity and no-stakes testing design of the assessment process, it was not required or possible to request and obtain written informed parental consent from the participants.

## Author note

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## CRediT authorship contribution statement

**Gyöngyvér Molnár:** Conceptualization, Research Design, Methodology, Investigation, Data curation, Writing – Original Draft, Reviewing and Editing. **Zoltán Hermann:** Research Design, Data curation, Methodology, Visualization, Writing – Reviewing and Editing.

## Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Appendix

**Appendix 1**
Sample of the analyses by grade and domain.

| Grade | Number of different students | Mathematics/Counting and basic numeracy skills | Reading/Precursors of reading skills | Science/Inductive reasoning |
|---|---|---|---|---|
| 1 | 16726 | 15684 | 15290 | 15142 |
| 2 | 7765 | 5327 | 5398 | 4643 |
| 3 | 9021 | 6244 | 5554 | 5552 |
| 4 | 10101 | 6876 | 6248 | 6547 |
| 5 | 10347 | 6103 | 5782 | 6442 |
| 6 | 11131 | 6773 | 6590 | 7308 |
| 7 | 8960 | 5346 | 5284 | 6123 |
| 8 | 4106 | 3181 | 2887 | 2738 |
| Total | 78157 | 55650 | 53150 | 39353/15258 |

**Appendix 2**
Number of schools and students in the sample in the pre-COVID and COVID years.

| | Grade 1 | Grades 2–4 | Grades 5–8 |
|---|---|---|---|
| Number of schools | | | |
| Pre-COVID years | 165 | 213 | 232 |
| 2020–21 academic year | 147 | 97 | 91 |
| 2021–22 academic year | 149 | 124 | 119 |
| Number of schools total | 272 | 301 | 316 |
| Number of students | | | |
| Mathematics/Counting and basic numeracy skills | | | |
| Pre-COVID years | 6069 | 9796 | 9764 |
| 2020–21 academic year | 4764 | 3842 | 4465 |
| 2021–22 academic year | 4851 | 4809 | 7174 |
| Reading/Precursors of reading skills | | | |
| Pre-COVID years | 6079 | 8496 | 9251 |
| 2020–21 academic year | 4621 | 4060 | 4616 |
| 2021–22 academic year | 4590 | 4644 | 6676 |
| Science | | | |
| Pre-COVID years | – | 9668 | 12912 |
| 2020–21 academic year | – | 3364 | 3705 |
| 2021–22 academic year | – | 3710 | 5994 |
| Inductive reasoning | | | |

(*continued on next page*)

**Appendix 2** (*continued*)

| | Grade 1 | Grades 2–4 | Grades 5–8 |
|---|---|---|---|
| Pre-COVID years | 5963 | – | – |
| 2020–21 academic year | 4608 | – | – |
| 2021–22 academic year | 4571 | – | – |

## Appendix 3

Descriptive statistics for the original variables without missing data imputation.

| | Grade 1 | | Grades 2–4 | | Grades 5–8 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Indicators for COVID years | | | | | | |
| 2020–21 academic year* | 0.30 | | 0.18 | | 0.18 | |
| 2021–22 academic year* | 0.31 | | 0.21 | | 0.27 | |
| School-level control variables | | | | | | |
| Share of disadvantaged students | 0.13 | 0.22 | 0.18 | 0.25 | 0.19 | 0.25 |
| Share of highly disadvantaged students | 0.07 | 0.16 | 0.09 | 0.18 | 0.10 | 0.18 |
| Share of students with special educational needs | 0.04 | 0.06 | 0.05 | 0.06 | 0.07 | 0.08 |
| Share of students in Grade 6 with mothers with a university degree, 2017–19 | 0.29 | 0.20 | 0.25 | 0.19 | 0.24 | 0.18 |
| Mean mathematics test score in the school in Grade 6, 2017–19 | −0.10 | 0.55 | −0.21 | 0.55 | −0.23 | 0.55 |
| Mean reading test score in the school in Grade 6, 2017–19 | −0.10 | 0.53 | −0.23 | 0.52 | −0.24 | 0.51 |
| Log school size | 5.76 | 0.67 | 5.66 | 0.65 | 5.65 | 0.63 |
| Type of municipality: village* | 0.29 | | 0.35 | | 0.36 | |
| Average income in the municipality | 1.54 | 0.33 | 1.48 | 0.35 | 1.47 | 0.35 |
| Student-level control variables | | | | | | |
| Gender: female* | 0.50 | | 0.49 | | 0.49 | |
| Age relative to expected age in the grade | 0.00 | 0.49 | 0.03 | 0.55 | 0.05 | 0.59 |
| Month of the achievement test | 9 | 0 | 10.96 | 0.49 | 10.97 | 0.52 |

Note. *Binary indicator variables.

## Appendix 4

Regression models of learning loss.

| | Grade 1 | | | Grades 2–4 | | | Grades 5–8 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Numeracy skills | Precursors of reading skills | Inductive reasoning | Mathematics | Reading | Science | Mathematics | Reading | Science |
| Indicators for COVID years | | | | | | | | | |
| 2020–21 academic year | −16.028*** | −4.965 | −8.219*** | −5.553 | −9.786*** | −2.588 | −2.046 | −3.890 | −6.944* |
| | (3.089) | (3.484) | (2.960) | (3.784) | (3.574) | (3.839) | (3.484) | (3.062) | (3.718) |
| 2021–22 academic year | −22.911*** | −9.895*** | −13.057*** | −20.429*** | −27.956*** | −21.946*** | −7.813** | −10.031*** | −8.864*** |
| | (3.498) | (3.595) | (3.184) | (4.307) | (4.044) | (4.335) | (3.241) | (3.165) | (2.782) |
| Control variables | | | | | | | | | |
| Gender: female | 0.808 | 14.758*** | 12.213*** | 2.471 | 19.302*** | 6.830*** | 3.763** | 27.281*** | 6.478*** |
| | (1.733) | (1.892) | (1.749) | (1.962) | (1.962) | (1.904) | (1.754) | (1.803) | (1.617) |
| Age relative to expected age in the grade | 6.023*** | 0.346 | 6.481*** | −18.855*** | −21.017*** | −21.955*** | −26.755*** | −30.821*** | −24.831*** |
| | (1.856) | (2.072) | (2.217) | (1.960) | (2.138) | (2.097) | (1.722) | (1.525) | (1.661) |
| Share of students with special educational needs | 37.295 | 11.127 | 48.781* | −40.798 | −12.354 | −24.382 | −31.728* | −45.074** | 1.778 |
| | (23.312) | (25.737) | (25.365) | (28.463) | (25.170) | (29.223) | (17.949) | (18.982) | (13.825) |
| Share of disadvantaged students | −61.536*** | −52.498** | −61.713*** | −38.079 | −53.710** | −70.572*** | −45.381*** | −53.106*** | −62.924*** |
| | (22.274) | (22.840) | (19.413) | (23.860) | (23.432) | (22.770) | (17.281) | (14.057) | (13.582) |
| Share of highly disadvantaged students | −5.067 | −0.631 | −16.212 | −11.385 | 1.519 | −9.488 | −6.258 | −13.752 | 0.593 |
| | (25.234) | (26.896) | (20.946) | (28.008) | (27.570) | (31.079) | (17.498) | (16.985) | (14.243) |
| Share of students in Grade 6 with mothers with a university degree, 2017–19 | 96.902*** | 108.612*** | 81.281*** | 87.850*** | 85.005*** | 56.895*** | 94.794*** | 62.220*** | 48.380*** |
| | (14.414) | (14.635) | (14.316) | (15.806) | (15.845) | (14.743) | (16.633) | (13.980) | (10.818) |
| Mean mathematics test score in the school in Grade 6, 2017–19 | −1.453 | 0.996 | −3.440 | −3.248 | −3.221 | −5.018 | −0.331 | 1.003 | −6.374 |
| | (7.262) | (6.353) | (6.143) | (6.322) | (6.829) | (6.426) | (5.315) | (5.182) | (3.894) |

(*continued on next page*)

**Appendix 4** (*continued*)

| | Grade 1 | | | Grades 2–4 | | | Grades 5–8 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Numeracy skills | Precursors of reading skills | Inductive reasoning | Mathematics | Reading | Science | Mathematics | Reading | Science |
| Mean reading test score in the school in Grade 6, 2017–19 | 18.387** | 15.662** | 20.359*** | 32.567*** | 30.555*** | 37.177*** | 26.746*** | 25.029*** | 34.040*** |
| | (7.186) | (7.399) | (6.116) | (9.248) | (10.854) | (8.597) | (7.740) | (7.825) | (5.312) |
| School with Grades 1–4 only | 12.510* | 4.862 | 14.504* | 7.791 | 6.215 | 2.243 | | | |
| | (7.074) | (9.060) | (7.426) | (8.542) | (8.744) | (7.400) | | | |
| Log school size | −5.520 | −4.423 | −3.606 | −7.442 | −6.151 | −6.399 | 2.208 | 3.512 | 1.987 |
| | (4.402) | (5.716) | (4.331) | (4.713) | (4.678) | (4.236) | (3.682) | (3.229) | (2.906) |
| Type of municipality: village | −0.382 | −3.219 | 1.582 | −12.443** | −10.743** | −9.706* | −0.501 | 5.520 | 5.649 |
| | (5.598) | (6.836) | (5.144) | (5.565) | (5.424) | (5.295) | (5.006) | (4.174) | (3.619) |
| Average income in the municipality | −9.308 | −18.554* | −6.209 | −2.969 | −4.651 | −10.782 | −10.769 | −7.308 | −5.979 |
| | (7.745) | (9.752) | (6.335) | (8.561) | (8.807) | (7.990) | (8.736) | (8.848) | (6.352) |
| Month of the achievement test | | | | 5.055 | 5.934* | 4.979 | 3.291 | 3.212 | 3.200 |
| | | | | (3.106) | (3.286) | (3.284) | (2.421) | (2.142) | (2.409) |
| Grade 3 | | | | 1.015 | 3.192 | 0.745 | | | |
| | | | | (3.030) | (3.218) | (3.131) | | | |
| Grade 4 | | | | −0.316 | 1.752 | −1.609 | | | |
| | | | | (3.212) | (3.115) | (3.126) | | | |
| Grade 5 | | | | | | | −0.002 | 1.842 | −2.587 |
| | | | | | | | (2.573) | (2.514) | (2.147) |
| Grade 7 | | | | | | | 5.587** | 4.158 | 0.667 |
| | | | | | | | (2.770) | (2.892) | (2.741) |
| Grade 8 | | | | | | | 8.045** | 9.964** | 4.953 |
| | | | | | | | (3.918) | (4.004) | (3.347) |
| Constant | 533.539*** | 528.987*** | 510.142*** | 496.563*** | 476.619*** | 515.795*** | 464.837*** | 452.638*** | 471.103*** |
| | (27.951) | (37.223) | (28.804) | (47.066) | (49.340) | (44.225) | (36.608) | (33.024) | (36.068) |
| Observations | 15,684 | 15,290 | 15,142 | 18,447 | 17,200 | 16,742 | 21,403 | 20,543 | 22,611 |

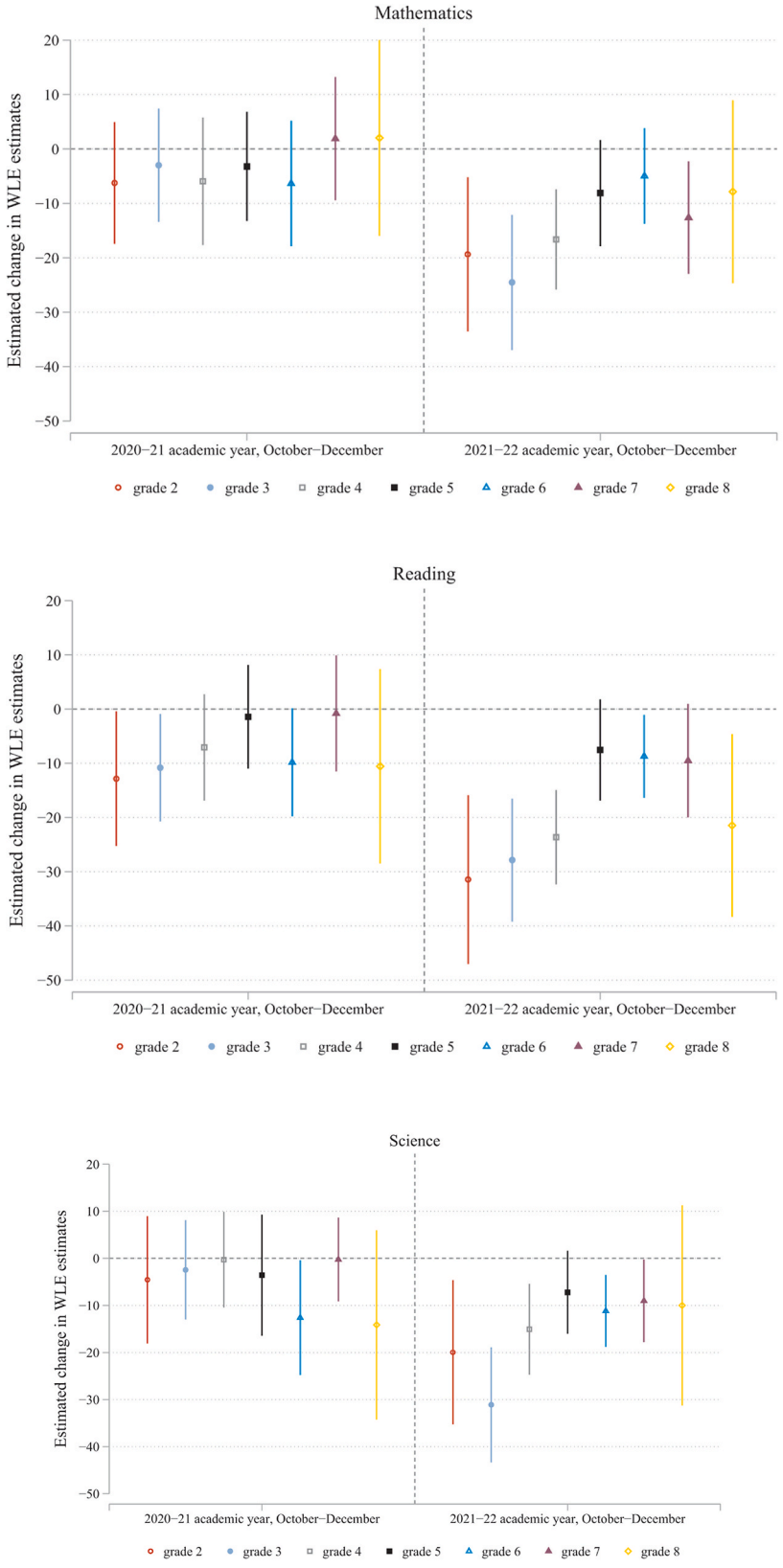
Note. Robust standard errors clustered at the school level in parentheses. ***p < .01, **p < .05, *p < .1.

**Appendix 5**

The equality of the estimated learning loss for 2020 and 2021 (F-test).

| Sample | Domain | Degrees of freedom 1 | Degrees of freedom 2 | F | Prob > F | Sign. |
|---|---|---|---|---|---|---|
| Grades 2–4 | Mathematics | 1 | 287 | 9.23 | .002 | *** |
| Grades 2–4 | Reading | 1 | 283 | 13.13 | .000 | *** |
| Grades 2–4 | Science | 1 | 276 | 13.40 | .000 | *** |
| Grades 5–8 | Mathematics | 1 | 303 | 2.73 | .099 | * |
| Grades 5–8 | Reading | 1 | 290 | 4.28 | .039 | ** |
| Grades 5–8 | Science | 1 | 292 | 0.28 | .592 | |
| Grades 2–4, low SES | Mathematics | 1 | 152 | 14.99 | .000 | *** |
| Grades 2–4, low SES | Reading | 1 | 152 | 13.83 | .000 | *** |
| Grades 2–4, low SES | Science | 1 | 150 | 24.35 | .000 | *** |
| Grades 5–8, low SES | Mathematics | 1 | 158 | 7.88 | .005 | *** |
| Grades 5–8, low SES | Reading | 1 | 150 | 6.42 | .012 | ** |
| Grades 5–8, low SES | Science | 1 | 155 | 0.76 | .382 | |
| Grades 2–4, mid- and high SES | Mathematics | 1 | 143 | 2.39 | .123 | |
| Grades 2–4, mid- and high SES | Reading | 1 | 139 | 5.08 | .025 | ** |
| Grades 2–4, mid- and high SES | Science | 1 | 135 | 3.82 | .052 | |
| Grades 5–8, mid- and high SES | Mathematics | 1 | 155 | 0.10 | .747 | |
| Grades 5–8, mid- and high SES | Reading | 1 | 151 | 0.59 | .440 | |
| Grades 5–8, mid- and high SES | Science | 1 | 148 | 0.02 | .864 | |
| Grade 1 | Basic maths skills | 1 | 269 | 3.98 | .046 | ** |
| Grade 1 | Reading precursor skills | 1 | 271 | 1.59 | .207 | |
| Grade 1 | Inductive reasoning | 1 | 269 | 2.01 | .156 | |
| Grade 1, low SES | Basic maths skills | 1 | 133 | 2.15 | .144 | |
| Grade 1, low SES | Reading precursor skills | 1 | 134 | 1.00 | .318 | |
| Grade 1, low SES | Inductive reasoning | 1 | 133 | 2.10 | .149 | |
| Grade 1, mid- and high SES | Basic maths skills | 1 | 142 | 2.09 | .149 | |
| Grade 1, mid- and high SES | Reading precursor skills | 1 | 143 | 0.72 | .394 | |
| Grade 1, mid- and high SES | Inductive reasoning | 1 | 142 | 0.49 | .482 | |

**Appendix 6. 2nd–8th-grade students' learning loss in mathematics, reading and science in the autumn term of the 2020–21 and 2021–22 academic years**




*Note.* Pre-pandemic samples: 2015, 2018 and 2019. Analyses were controlled for school characteristics and the effect of students' gender and age. Point estimates and 95% confidence interval.

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