Preprint (not peer reviewed). Cite as: Betthäuser, B.A., Bach-Mortensen, A.M., Engzell, P. (2022). A systematic review and meta-analysis of the impact of the COVID-19 pandemic on learning. SocArXiv. April xx.

A systematic review and meta-analysis of the impact of the COVID-19 pandemic on learning

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How has the COVID-19 pandemic affected learning progress among school-age children? Two years after the onset of the pandemic, a growing number of studies have addressed this question, but findings vary depending on context. We conduct a pre-registered systematic review, quality appraisal and meta-analysis of 34 studies across 12 countries to assess the magnitude of the effect of the pandemic on learning and the role of different factors in moderating this effect. We find a significant overall learning deficit early in the pandemic (Cohen's $d = -0.17$, 95 c.i. [−0.22, −0.13]), which persists over time. Forgone learning was particularly large among children from low socio-economic backgrounds and in contexts with high excess mortality, longer school closures, and less-developed digital learning infrastructures. Future research should assess the effects of the COVID-19 pandemic in low- and middle-income countries, as existing studies mainly focus on high-income countries.

The COVID-19 pandemic has led to one of the largest disruptions to learning in history. To a large extent this is due to school closures, which are estimated to have affected 95 percent of the world's student population.[1] But even when face-to-face teaching resumed, instruction has often been compromised by hybrid teaching, and by teachers or children having to quarantine and missing classes. The effect of limited face-to-face instruction is likely compounded by the pandemic's consequences for children's out-of-school learning environment, as well as their mental and physical health. Lockdowns have restricted children's movement and their ability to play, meet other children, and engage in extra-curricular activities. Children's well-being and family relationships have also suffered due to economic uncertainties and conflicting demands of work, care and learning. These negative consequences are likely to be most pronounced for children from low socio-economic family backgrounds, exacerbating pre-existing educational inequalities.

It is critical to understand how the COVID-19 pandemic has affected children's learning progress. In this work, we use the term 'learning deficit' to refer to effects of the pandemic on learning. This may encompass both a delay in expected learning progress, as well as a loss of skills and knowledge already gained. The COVID-19 learning deficit is likely to affect children's life chances through their education and labor market prospects. At the societal level, it can have important implications for growth, prosperity, and social cohesion. As policy-makers across the world are seeking to limit further learning deficits and to devise policies to recover incurred ones, assessing the current state of learning is crucial. A careful assessment of the COVID-19 learning deficit also is also necessary for us to be able to weigh the true costs and benefits of school closures.

We conduct a systematic review and meta-analysis of the evidence on COVID-19 learning deficits two years into the pandemic. Our first contribution is to review the existing evidence and appraise its geographic reach and quality. More specifically, we ask (a) How much available evidence is there on the effect of the COVID-19 pandemic on learning?, (b) Which countries does the available evidence cover?, and (c) What is the quality of the existing evidence?

Our second contribution is to harmonize, synthesize and meta-analyze the existing evidence, with a special attention to variation across different sub-populations and country contexts. Based on the studies we identify, we ask (d) What is the magnitude of the overall effect of the COVID-19 pandemic on learning?, (e) How has the magnitude of the learning deficit evolved since the beginning of the pandemic?, (f) To what extent has the pandemic reinforced inequalities between children from different socio-economic backgrounds? (g) Are there differences in the magnitude of the learning deficit between subject domains (math and reading) and between grade levels (primary and secondary)?, and (h) To what extent do contextual factors, such as country context, excess mortality, length of school closure, and teachers' use of digital learning tools moderate the effect of the pandemic on learning progress? Below, we report our answers to each of these questions in turn.

The state of the evidence

Our systematic review identified 34 studies on the effect of the COVID-19 pandemic on learning. As shown in Figure 1, an initial literature search yielded 5,153 hits after removal of duplicates, which were double-screened by the first two authors. We also hand-searched relevant preprint repositories and policy databases, from which we identified 97 studies that were also double-screened. The initial search process identified 28 eligible studies. Studies had to measure learning using standardized test scores to be eligible for inclusion. To ensure that our study selection was as up-to-date as possible, we conducted a full forward and backward citation search of all included studies on February 15, 2022. This allowed us to identify 6 additional studies. Most of these studies were published after the initial search, which illustrates that the body of evidence on the effect of the pandemic on learning continues to expand.

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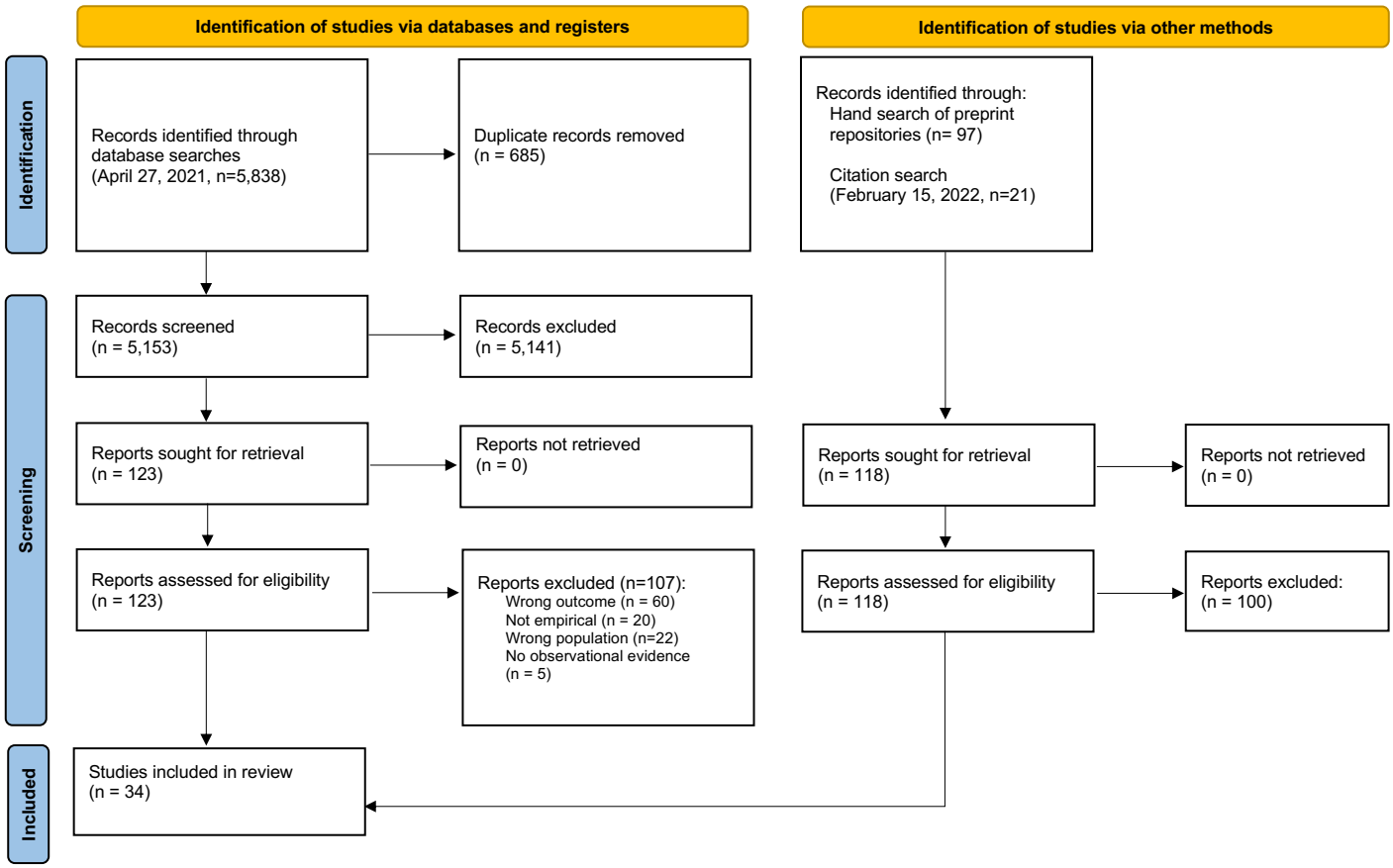

Figure 1: Study identification and selection process (PRISMA diagram)

The geographic reach of the evidence is limited. Table 1 shows all identified studies, grouped by country. As shown in Table 1, studies often provide multiple estimates, typically referring to different subjects (math and reading) or school grades. The number of estimates (n=235) is therefore larger than the number of studies (n=34). 12 countries are represented: Australia, Belgium, Brazil, Denmark, England, Germany, Italy, Mexico, the Netherlands, South Africa, Switzerland, and the United States. About half of the estimates ($n = 95$) are from the United States, 64 are from the United Kingdom, a further 36 are from other European countries, and the remaining 10 estimates are from Australia, Brazil, Mexico, and South Africa. As this list shows, there is a strong over-representation of studies from high-income countries, a dearth of studies from middle-income countries, and no studies from low-income countries. This skewed representation should be kept in mind when interpreting the existing evidence on COVID-19 learning deficits.

The quality of evidence is mixed. We assessed the quality of the evidence using an adapted version of the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool.[34] More specifically, we analyzed the risk of bias of each estimate from confounding, sample selection, classification of treatments, missing data, the measurement of outcomes, and the selection of reported results. The second author performed the risk of bias assessments, which were independently checked by the first and third author. We then assigned each study an overall risk of bias rating (low, moderate, serious, or critical) based on the estimate and domain with the highest risk of bias. In line with ROBINS-I guidance, we excluded all studies rated 'critical' ($n = 2$).[34]

Figure 2*A* shows the distribution of all estimates according to their risk of bias ratings in each domain, as well as the distribution of overall risk of bias . The overall risk of bias was considered 'serious' for 48% of estimates, 'moderate' for 36% of estimates, and 'low' for only 8% of estimates. As shown in Figure 2*A*, common sources of potential bias were confounding, sample selection, and missing data. Studies rated at risk of confounding typically compared only two time points, without accounting for longer time trends in learning progress. The direction of bias in this case is unclear. For other sources of bias, the expected consequence is most often an underestimation of COVID-19 learning deficit. The main causes of selection bias were the use of convenience samples and/or insufficient consideration of self-selection by schools or students. Several studies found evidence of selection bias, often with students from a low socio-economic background or schools in deprived areas being underrepresented post- as opposed to pre-pandemic, but this was rarely adjusted for. Some studies also reported a higher amount of missing data post-pandemic, again typically without adjustment, and several studies did not report any information on missing data.

No evidence of publication bias. Publication bias can occur if authors self-censor to conform to theoretical expec-

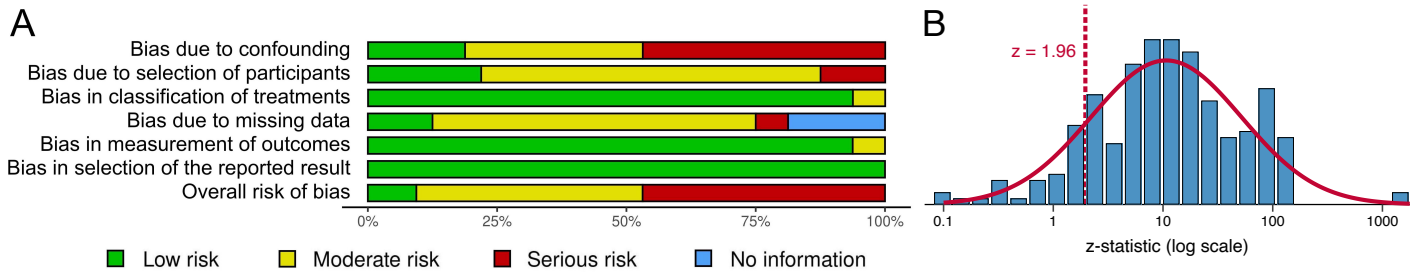

Figure 2: Risk of bias and publication bias. (A) Domain-specific and overall distribution of estimates of COVID-19 learning deficits by risk of bias rating using ROBINS-I, (B) z-curve: Distribution of the z-scores of all estimates.

Table 1: Studies by country

Country	Studies
Australia (4)	Gore et al. 2021 (4)[2]
Belgium (4)	Gambi and De Witte 2021 (2),[3] Maldonado and De Witte 2021 (2)[4]
Brazil (2)	Lichand et al. 2021 (2)[5]
Denmark (7)	Birkelund et al. 2021 (7)[6]
Germany (6)	Depping et al. 2021 (4),[7] Schult et al. 2021 (2)[8]
Italy (1)	Contini et al. 2021 (1)[9]
Mexico (2)	Hevia et al. 2022 (2)[10]
Netherlands (16)	Engzell et al. 2021 (8),[11] Haelermans et al. 2021 (2),[12] Schuurman et al. 2021 (6)[13]
South Africa (2)	Ardington et al. 2021 (2)[14]
Switzerland (2)	Tomasik et al. 2020 (2)[15]
United Kingdom (64)	Blainey et al. 2020a (10),[16] Blainey et al. 2021b (12),[17] Blainey et al. 2021c (12),[18] Blainey et al. 2021d (12),[19] Department for Education 2021a (6),[20] Department for Education 2021b (2),[21] GL Assessment 2021 (4),[22] Rose et al. 2021a (2),[23] Rose et al. 2021b (4)[24]
United States (95)	Domingue et al. 2021a (8),[25] Domingue et al. 2021b (4),[26] Kogan and Lavertu 2021a (1),[27] Kogan and Lavertu 2021b (9),[28] Kozakowski et al. 2021 (12),[29] Kuhfeld et al. 2020 (12),[30] Lewis et al. 2021 (12),[31] Lewis and Kuhfeld 2021 (12),[32] Pier et al. 2021 [MAP] (10), Pier et al. 2021 [Star] (10), Pier et al. 2021 [iReady] (5)[33]

Note: Countries and correspondeing studies on COVID-19 learning deficits. The number of estimates are shown in brackets, by country and study respectively; full references are indicated by superscript and listed in the bibliography.

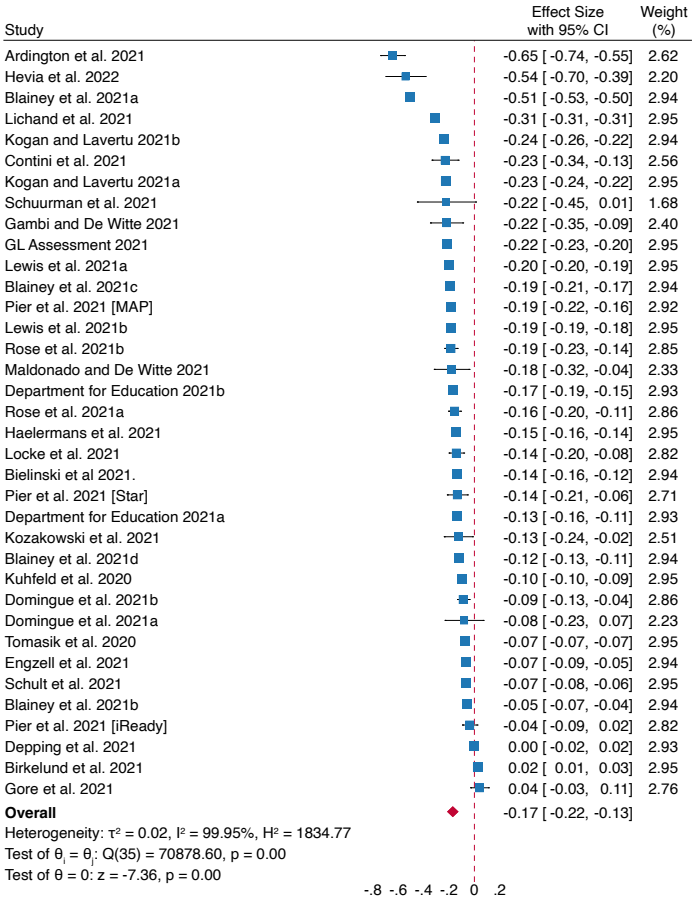

Figure 3: Forest plot showing individual estimates by study (averaged across subject and grade level) and pooled effect size estimate.

tations, or if journals favor statistically significant results. To mitigate this concern, we include not only published papers, but also unpublished working papers and 'gray literature', such as policy reports. Moreover, Figure 2B tests for publication bias by showing the distribution of z-statistics for the effect size estimates of all identified studies. The dotted line indicates $z = 1.96$ ($p = 0.05$), the conventional threshold for statistical significance. The overlaid curve shows a normal distribution. If there was publication bias, we would expect a spike just above the threshold, and a slump just below it. There is no indication of this, so publication bias does not seem to be a major concern.

Results

Having assessed the quality of the existing evidence, we now present the substantive results of our meta analysis on the magnitude of COVID-19 learning deficits, and on how learning deficits vary over time, across different groups of students, and across different country contexts.

The COVID-19 pandemic led to substantial learning deficits. Figure 3 shows the effect sizes that we extracted from each study (averaged across grades and learning subject) as well as the pooled effect size (red diamond). Effects are expressed in standard deviations, using Cohen's *d*. Estimates are pooled using inverse variance weights. The pooled effect size across all studies is $d = -0.17$. Under normal circumstances, students generally improve their performance by around 0.4 standard deviations per school year.[35,36,37] Thus, the overall effect of $d = -0.17$ suggests that students lost out on 0.17/0.4, or about 42%, of a school year's worth of learning. On average, the pandemic has led to a substantial learning deficit.

Learning deficits arise early in the pandemic and persist over time. There are conflicting expectations on how the learning deficit may develop over time. One may expect that the initial shock of the pandemic drives learning deficits. School closures, the psychological stress associated with an unprecedented health crisis, and the need for children, parents, and teachers to adjust to learning and working from home are likely to have slowed children's learning progress or even led children to lose already acquired knowledge and skills. Moreover, there have been concerns that the ongoing health crisis would lead early deficits in learning to accumulate further over time.[38] Even after schools reopened, learning has been compromised by classes being taught in hybrid format, and by teachers or children having to quarantine and missing class. Indeed, existing research on teacher strikes in Belgium[39] and Argentina,[40] shortened school years in Germany,[41] and disruptions to education during World War II[42] suggests that learning deficits are difficult to compensate and tend to persist in the long run. By contrast, one may also expect that children would catch up on foregone and lost learning after teachers and families have had time to adjust to the new learning conditions, and once structures for online learning have been set up, and policy initiatives to compensate early learning deficits—including the acquisition and distribution of digital learning equipment, or the organization of tutoring programs and summer schools—have been put in place.

Figure 4 plots the magnitude of estimated learning deficits (on the vertical axis) by the date of measurement (on the horizontal axis). The size of the circles indicates the sample size for a given estimate and the smoothed line displays a running average. The figure shows that learning deficits opened up early in the pandemic and have neither closed nor widened since then. This suggests that efforts by children, parents, teachers, and policy-makers to adjust to the changed circumstance have been successful in preventing further learning deficits but so far have been unable to reverse them.

The pandemic exacerbated educational inequality. Existing research on the development of learning gaps during summer vacations,,[43,44] disruptions to schooling during the Ebola outbreak in Sierra Leone and Guinea,[45] and the 2005 earthquake in Pakistan,[46] suggests that the suspension of face-to-face teaching increases educational inequality between children from different socio-economic backgrounds. The effect of the COVID-19 pandemic on learning progress is likely to have been particularly pronounced for children from low socio-economic backgrounds. These children have been more affected by school closures than children from more advantaged backgrounds.[47] Moreover, they are likely to be disadvantaged with respect to their access and ability to use digital learning technology, the quality of their home learning environment, and the learning support they receive from teachers and parents.[48,49]

Most studies we identified address socio-economic inequality, attesting to the importance of the issue. Because studies use different measures of socio-economic background (e.g., parental income, parental education, free school meal eligibility, neighborhood disadvantage), as well as different scales, pooling the estimates is not possible. Instead, we have coded all estimates according to whether they indicate a positive, negative, or no effect of the pandemic on learning inequality. Figure 5 displays this information. Estimates that indicate an increase in inequality are shown on the right, those that indicate a decrease on the left, and those that suggest no change in the middle. Squares represent estimates on the effect of the pandemic on inequality in reading performance, and circles represent estimates on the effect of the pandemic on inequality in math performance. The shading represent when in the pandemic educational inequality was measured: 0–6 months, 7–12 months, or 13–19 months after the onset of the pandemic in March 2020. Estimates are also arranged horizontally by grade level. A large majority of estimates indicate an increase in educational inequality between children from different socio-economic backgrounds. This holds for both math and reading, across primary and secondary education, at each stage of the pandemic, and independently of how socio-economic background was measured.

Learning deficits are larger in math than in reading. Existing research on summer learning deficits,[43,50] student absenteeism,[51,52] and extreme weather events,[53] suggests that learning progress in mathematics is more dependent on formal instruction than is reading. This might be due to parents being better equipped to help their children with reading, and children advancing their reading skills (but not their math skills) when reading for enjoyment outside of school. This leads to the expectation that COVID-19 learning deficits in math exceed those in reading. Figure 6*A* supports this expectation: estimated learning deficits are larger for math (mean −0.192, median −0.190) than for reading (mean −0.130, median −0.115).

Learning deficits do not vary across grade levels. One may expect learning deficits to be smaller for older than for younger children, as older children may be more autonomous in their learning and better able to cope with

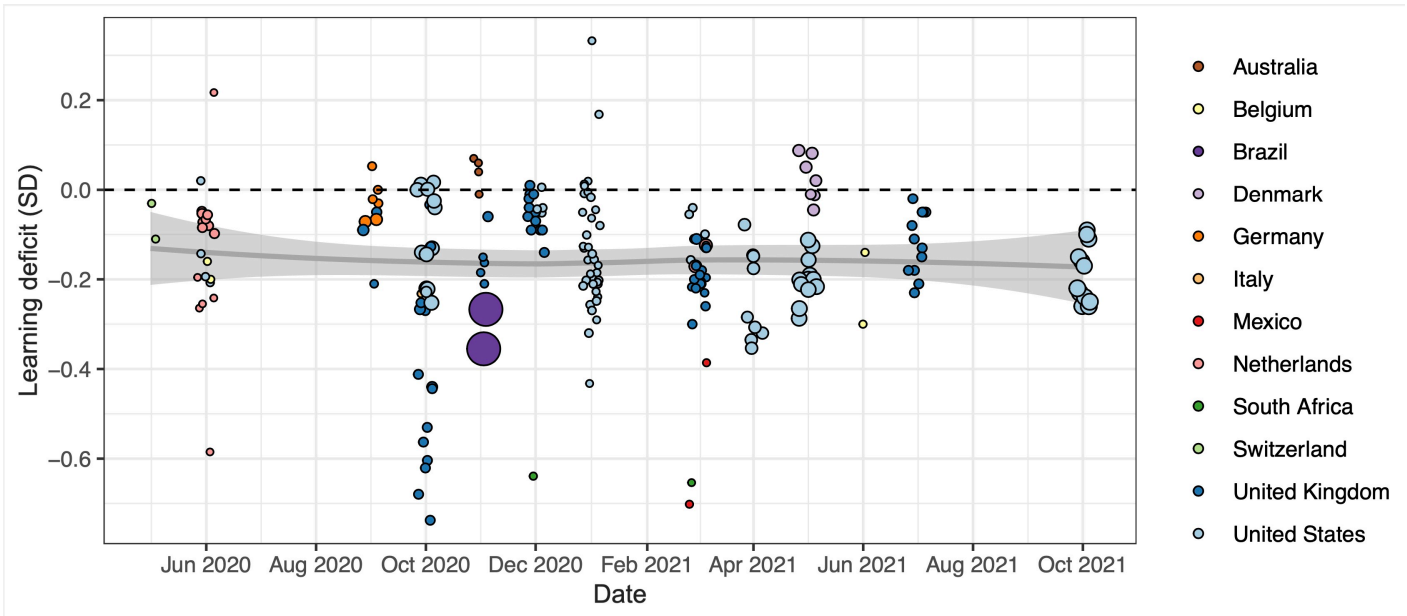

Figure 4: Estimates of COVID-19 learning deficits by date of measurement.

a sudden change in their learning environment. Figure 6*B* shows the central tendency and distribution of estimates separately for primary and secondary students. Contrary to expectation, we find no marked difference in the learning deficits between younger and older students. Note, however, that secondary students were subject to longer school closures in some countries, such as Denmark,[6] based partly on the assumption that they would be better able to learn from home. This may have offset any advantage that older children would otherwise have had in learning from home.

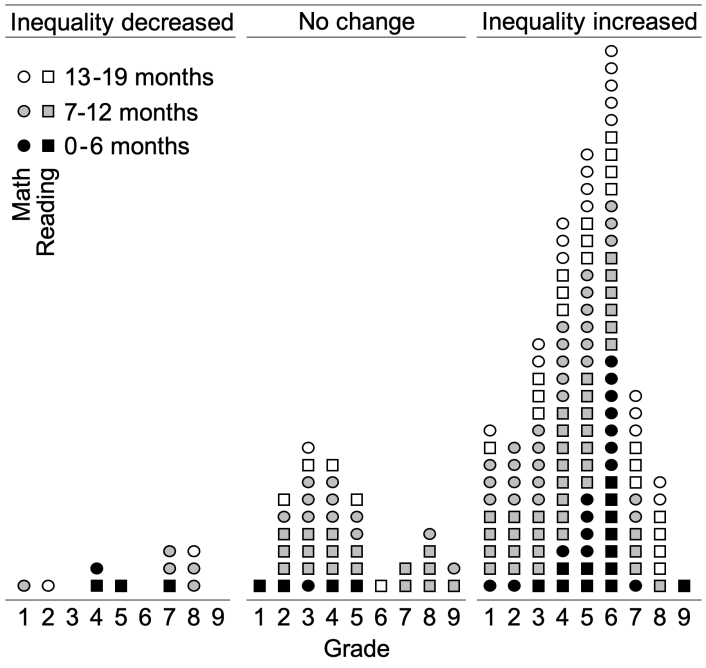

Figure 5: Harvest plot of the evidence on the effect of the pandemic on educational inequality. Each circle/square refers to one estimate of over-time change in inequality in math/reading performance. Estimates that find a decrease/no change/increase in inequality are grouped on the left/middle/right. Within these categories, estimates are ordered horizontally by grade level. Shading indicates when in the pandemic measure was taken.

Learning deficits are larger in poorer countries. Aside from the individual-level factors examined above, different society-level factors are likely to moderate the effect of the pandemic on children's learning progress. The pandemic can be expected to have exacerbated not only the educational gap between children from different socioeconomic backgrounds, but also between richer and poorer countries.[54,55]

Low and middle-income countries were already struggling with a learning crisis before the pandemic. Despite large expansions of the proportion of children in school, children in low and middle-income countries still perform poorly by international standards, and inequality in learning remains high.[56,57] The pandemic is likely to deepen this learning crisis and to undo past progress made. Schools in low- and middle-income countries have not only been closed for longer, but have also had fewer resources to facilitate remote learning.[58,59] Moreover, the economic resources, ICT equipment and ability of children, parents, teachers, and governments to support learning from home is likely to be lower in low- and middle-income countries.[55]

As discussed above, most evidence on COVID-19 learning deficits comes from high-income countries. We found no studies on low-income countries that met our inclusion criteria, and evidence from middle-income countries is limited to Brazil, Mexico and South Africa. Figure 6*C* groups the estimates of COVID-19 learning deficits in these three middle-income countries together and compares them to estimates from high-income countries. The learning deficit is appreciably larger in middle-income countries (mean −0.500, median −0.513) than in high-income countries (mean −0.149, median −0.143). In fact, the 3 studies on middle-income countries in our sample[14,10,5] are among the 4 studies re-

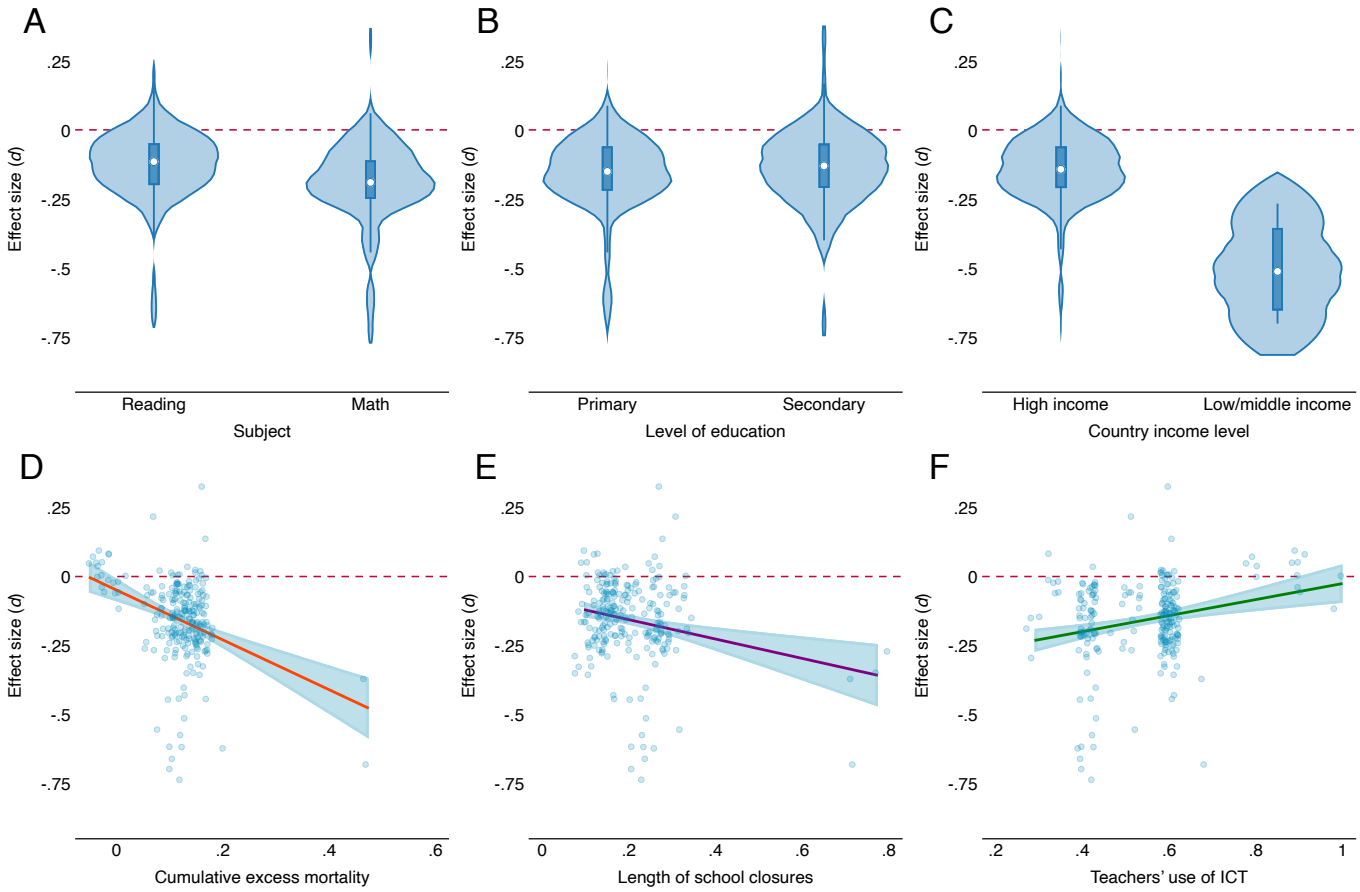

Figure 6: Variation in estimated learning deficits across individual- and country-level characteristics: (*A*) Learning subject, (*B*) Level of education, (*C*) Country income level, (*D*) Cumulative excess mortality, (*E*) Length of school closures, (*F*) Teachers' use of information and communications technology (ICT).

porting the largest estimates of learning deficits in Figure 3.

Higher excess mortality is associated with larger learning deficits. Variation in the pandemic's severity across countries and over time can be expected to have implications for the COVID-19 learning deficit. Higher incidences of infection and mortality due to the pandemic are likely to be associated with increased psychological and physical strain on children, parents, and teachers. A more severe course of the pandemic also implies more drastic measures to contain the virus, including (but not limited to) school closures, hybrid learning, curfews and teleworking, and in turn more obstacles to learning.

We measure the severity of the pandemic as the cumulative excess mortality at the country level. This measure is preferable over case numbers or registered COVID-19 deaths, which are difficult to compare across countries. Figure 6*D* plots all estimates of COVID-19 learning deficits (on the vertical axis) against excess mortality (on the horizontal axis) in the relevant country and at the date when learning deficits where measured. It shows a clear pattern, where learning deficits are higher in countries that have experienced a more severe course of the pandemic.

Longer school closures are associated with larger learning deficits. The pandemic has presented various challenges to students' learning, but the largest of these has arguably been the suspension of face-to-face teaching, which is estimated to have affected 95 per cent of the world's student population.[58,59] Remote learning may be a poor substitute for face-to-face learning. This is true particularly when it is implemented without adequate preparation, teacher training and availability of digital learning tools in children's homes.

To examine the relationship between school closures and learning deficits, we collated data from the UNESCO school closures database[60] and the US School Closure and Distance Learning Database.[47] Figure 6*E* plots all estimates of COVID-19 learning deficits against the cumulative length of school closures up until the date in the pandemic on which a given measure of learning deficit was taken. It shows that estimated learning deficits are larger in contexts where face-to-face teaching was suspended for longer stretches of time.

Teacher use of ICT is associated with smaller learning deficits. The quality of digital learning infrastructure, as well as children's and teacher's ability to use it, is likely to influence the effectiveness of remote learning.[61] As such, it is a key concern in ongoing policy debates over how to recover

lost and foregone learning, and how to limit further learning deficits in the future. We examine the relationship between learning deficits and teachers' use of information and communications technology (ICT) in Figure 6*F*. Information on ICT use in school was collected in the 2018 OECD Teaching and Learning International Survey (TALIS) and measures country-level variation in teachers' use of ICT prior to the pandemic (see *Methods*). Figure 6*F* supports the expectation that teachers' experience with using ICT is helpful in limiting learning deficits. Learning deficits are smaller or absent in countries, such as Denmark,[6] where teachers report frequent ICT use.

Discussion

Two years into the COVID-19 pandemic, there is still insufficient knowledge about its consequences for the learning progress of school-age children. This paper makes two main contributions to better understand the state of the evidence. First, it systematically reviews the existing literature on the effect of the pandemic on learning among school-age children and appraises its geographic reach and quality. Second, it harmonizes, synthesizes and meta-analyzes the existing evidence in order to examine the extent to which the pandemic has affected learning, and how this varies across different groups of students and country contexts.

We identify a sizable and growing body of evidence on the effects of the COVID-19 pandemic on learning. However, existing studies primarily focus on high-income countries, while there is a dearth of evidence from low- and middle-income countries. This is particularly concerning because the small number of existing studies from middle-income countries suggest that learning deficits have been particularly severe in those countries. Learning deficits are likely to be even larger in low-income countries, considering that these countries already faced a learning crisis before the pandemic, generally implemented longer school closures, and were under-resourced and ill-equipped to facilitate remote learning. It is critical that this evidence gap on low- and middle-income countries is addressed swiftly, and that the infrastructure to collect and share data on educational performance in middle- and low-income countries is improved.

About half of the studies that we identified were rated as having a serious risk of bias. Future studies should minimize risk of bias in estimating learning deficits by employing research designs that appropriately account for common sources of bias. These include a lack of accounting for secular time trends, non-representative samples, and imbalances between treatment and comparison groups. That being said, we find little reason to expect that these potential sources of bias would inflate estimates of COVID-19 learning deficits. On the contrary, they are likely to lead to an underestimation of learning deficits. Non-representative samples, selective attrition, and missing data are likely to lead to an under-representation of disadvantaged students, who experience larger learning deficits.

Our meta-analysis suggests that the COVID-19 pandemic has led to substantial learning deficits. The pooled effect size of $d = -0.17$, implies that students lost out on 0.17/0.4, or about 42%, of a school year's worth of learning. This confirms initial concerns that the pandemic would cause substantial harm to student learning .[35,62] But our results also show that fears of an accumulation of learning deficits as the pandemic continues have not materialized.[63,38] On average, learning deficits emerged early in the pandemic and have neither closed nor widened.

The persistence of learning deficits two years into the pandemic highlights the need for well-designed, well-resourced and decisive policy initiatives to recover learning deficits. Policy-makers, schools, and families will need to identify and realize opportunities to complement and expand on regular school-based learning. One clear opportunity lies in use of the often extensive summer holidays, to offer summer schools and learning camps. Other promising avenues include extending school days and school weeks, and organizing and scaling up tutoring programs. Further potential lies in developing, improving, publicizing and providing access to learning apps, online learning platforms, or educational TV programs that are free at the point of use. Many countries have already begun investing significant resources to capitalize on these opportunities. If the momentum of these policy efforts is maintained and expanded, the disruptions to learning during the pandemic may prove to be a window of opportunity to improve and extend the education afforded to children.

Most studies that we identify find that learning deficits have been largest for children from disadvantaged socio-economic backgrounds. This holds throughout the pandemic, in multiple countries, for both math and reading, across grade levels, and independently of how socio-economic background is measured. The pandemic has thus exacerbated educational inequalities that were already large before the pandemic.[64,65] Policy initiatives to compensate learning deficits need to prioritize support for children from low socio-economic backgrounds in order to allow them to recover the learning they lost during the pandemic.

Comparing estimates of learning deficits across subjects, we find that learning deficits tend to be larger in math than in reading. As noted above, this may be due to the fact that parents and children have been in a better position to compensate school-based learning in reading by reading at home. Accordingly, there are grounds for policy initiatives to prioritize the compensation of learning deficits in math and other science subjects.

Our analysis of macro-level moderators suggests that COVID-19 learning deficits are higher in countries that experienced a more severe course of the pandemic, as measured by cumulative excess mortality. This is likely to be due to the higher overall psychological and physical strain of the health crisis on children, parents, and teachers, which was intensified by restrictive measures to contain the spread of the virus. One important measure through which governments have sought to contain the spread of the virus has been the suspension of face-to-face teaching. Confirming warnings by experts early in the pandemic, our meta-analysis shows that longer school closures are associated with larger learning deficits. This finding highlights the importance of carefully weighing the costs to learning incurred by school closures against possible health benefits from con-

taining the spread of infections. This is true particularly considering the mixed evidence on the effectiveness of school closures in containing the spread of COVID-19.[66,67]

While remote learning is likely to remain a poor substitute for face-to-face instruction, having an adequate infrastructure for digital learning is likely to be critical for limiting learning deficits in the event of school closures. We find that teachers' use of information and communication technology (ICT) prior to the onset of the pandemic moderates the effect of the pandemic on learning progress. Countries, such as Denmark,[6] in which ICT use was widespread before the pandemic saw little or no learning deficits during the pandemic. Governments should upgrade the infrastructure for digital learning, as this will not only guard against adverse consequences of future disruptions to schooling, but also provide a means to recovering existing learning deficits by complementing regular, school-based instruction.

Our analysis provides important evidence of how the COVID-19 learning deficit has varied between different groups of students and across countries. Given the limited reach of the existing evidence, we do not seek to identify the causal role of specific factors. A fruitful avenue for future research will be to use quasi-experimental designs to reveal how specific factors can account for individual and society-level variation in the extent of COVID-19 learning deficits. The considerable variation across sub-populations and country contexts highlights the need to better understand this variation, and identify mechanisms that can guide policy measures for limiting and counteracting learning deficits.

Methods

Eligibility criteria. We considered all types of primary research, including peer-reviewed publications, preprints, working papers, and reports for inclusion. To be eligible for inclusion, studies had to measure learning progress using test scores that could be standardized across studies using Cohen's *d*. Moreover, studies had to be in English, Danish, Dutch, French, German, Norwegian, Spanish or Swedish.

Search strategy and study identification. We identified eligible studies using the following steps. First, we developed a Boolean search string defining our population (school-aged children), exposure (the COVID-19 pandemic), and outcomes (e.g., math and reading) of interest. The full search string can be found in the Appendix. We used this string to search the following academic databases: Coronavirus Research Database, Education Database, ERIC, International Bibliography of the Social Sciences (IBSS), Politics Collection (PAIS index, policy file index, political science database, and worldwide political science abstracts), Social Science Database, Sociology Collection (applied social science index [ASSIA] and abstracts, sociological abstracts, and sociology database), CINAHL, and Web of Science. The search was conducted on April 27, 2021. Given the focus on the COVID-19 Pandemic, we restricted our search to papers published in 2020 or later. Second, we hand-searched multiple preprint, working paper, and policy document repositories. Specifically, we hand-searched SSRN, MPRA, IZA, NBER, OSF Preprints, PsyArXiv, SocArXiv, and EdArXiv, and relevant policy websites, including, but not limited to, the websites of the Organisation for Economic Co-operation and Development, the United Nations, the World Bank, and the Education Endowment Foundation. Third, we periodically posted our protocol via Twitter in order to crowdsource additional relevant studies not identified through the search. Last, to ensure that our analysis was comprehensive in terms of recent and relevant research, we conducted a final manual forward and backward citation search of all eligible studies identified by the above steps. This process was conducted by ABM on February 14, 2022.

Data extraction. From the studies that met our inclusion criteria we extracted the estimates of the effect of the pandemic on learning progress, separately for math and reading and for different school grades. We also extracted the corresponding sample size, standard error, date(s) of measurement, author name(s), and country. Last, we recorded whether studies differentiate between children's socio-economic background, which measure was used to this end, and whether studies found an increase, decrease or no change in learning inequality. We contacted study authors, if any of the above information was missing in the study. Data extraction was performed by BB and validated independently by ABM, with discrepancies resolved through discussion and by conferring with PE.

Measurement and standardization. We standardized all estimates of the effect of the pandemic on learning reported using Cohen's *d*, which expresses effect sizes in terms of standard deviations. Cohen's d is calculated as the difference in the mean learning gain in a given subject (math or reading) over two comparable periods before and after the onset of the pandemic, divided by the pooled standard deviation of learning progress in this subject: $d = \frac{\bar{x}_1 - \bar{x}_2}{s}$, where $s = \sqrt{\frac{\left(s_1^2 + s_2^2\right)}{2}}$. Effect sizes expressed as β coefficients were converted to Cohen's d using $d = \frac{\beta}{se} \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$.

Subject. We include a binary indicator for whether the study outcome is math or reading. One study did not differentiate the outcome but includes a composite of math and reading scores.[15]

Level of education. We distinguish between primary and secondary education. We first consulted the original studies for this information. In cases where the level of education was undetermined, students' age was used in conjunction with information about education systems from external sources.[68]

Country income level. We follow the World Bank's classification of countries into four income groups: low, lower-middle, upper-middle, and high-income. Three countries in our sample place are in the upper-middle group: Brazil, Mexico and South Africa. Remaining countries are high-income.

Excess mortality. We use data on all-cause mortality from the World Mortality Dataset.[69] We first model monthly deaths in the years 2015–2019 as a function of 12 month indicators and a linear trend in year that are allowed to

vary by country:

$$deaths_{ct} = \alpha_c + \sum_{m=1}^{12} \delta_{cm} month + \gamma_c year + \varepsilon_{ct}$$

We then extract predicted values from this model for the period 2020–2021, which we label $\widehat{deaths}_{ct}$ (c for country, t for time). Next, we calculate excess mortality from observed deaths:

$$excess_{ct} = \frac{deaths_{ct}}{\widehat{deaths}_{ct}} - 1$$

The variable we enter into our analysis is a cumulative average of estimated excess deaths from March 2020 until time t when learning was measured.

Length of school closures. We operationalize school closures as the share of time (starting in March 2020) that schools had been closed until learning was measured. Our primary source is the UNESCO school closures database.[60] We complement this information with data from the US School Closure and Distance Learning Database[47] that allows us so extract state-level averages for studies that sample a single US state.

Teachers' use of ICT. We use survey data on the percentage of teachers in a country who report regularly using information and communications technology (ICT) in teaching. This information is from the 2018 round of OECD's Teaching and Learning International Survey (TALIS).[70] The variable reflects the share of teachers who answer the question "I let students use ICT for projects or class work" with "frequently" or "always".

Data synthesis. We synthesized our data using three synthesis techniques. First, we use random-effects models to generate a forest plot, based on the estimates of the effect of the pandemic on learning progress from the studies we identified. We pool estimates using inverse variance weights to calculate an overall effect size (see Figure 3).[71] Second, due large variation across studies in the measures of socioeconomic background they use, we coded all estimates according to whether they indicate a positive, negative, or no effect of the pandemic on learning inequality. We visualize the reported effects using a harvest plot (see Figure 5).[72] Third, given that the limited country- and overtime variation precludes multi-variate analyses, we examine the bivariate association between COVID-19 learning deficits and a range of individual-level and country-level covariance using a series of violin and scatter plots (see Figure 6).

Pre-registration and data availability. A protocol of our systematic review and meta-analysis was prospectively registered in the International Prospective Register of Systematic Reviews (CRD42021249944). We will share all information and data needed to replicate our findings on the Open Science Framework (`https://osf.io/`) following journal publication.

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