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Lakha, F., King, A., Swinkels, K. et al. (1 more author) (2022) Are schools drivers of COVID-19 infections — an analysis of outbreaks in Colorado, USA in 2020. *Journal of Public Health*, 44 (1). e26-e35. ISSN 1741-3842

<https://doi.org/10.1093/pubmed/fdab213>

This is a pre-copyedited, author-produced version of an article accepted for publication in *Journal of Public Health* following peer review. The version of record, F Lakha, A King, K Swinkels, A C K Lee, Are schools drivers of COVID-19 infections—an analysis of outbreaks in Colorado, USA in 2020, *Journal of Public Health*, Volume 44, Issue 1, March 2022, Pages e26–e35 is available online at: <https://doi.org/10.1093/pubmed/fdab213>

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Are schools drivers of COVID-19 infections – an analysis of outbreaks in Colorado

F Lakha, A King, K Swinkels, A C K Lee

ABSTRACT

Background: The impact of school closures and reopening on transmission of SARS-CoV-2 in the wider community remains contested. School closure is not a long-term solution especially in a pandemic with no clear end in sight.

Methods: Data on outbreaks from Colorado, USA, in 2020, alongside data on implemented public health measures were analysed to gain insights on the role of educational institutions on transmission plus the relationship between settings and the impacts of policies implemented.

Results: There were three waves with a total of 3,169 outbreaks involving 61,650 individuals. The first was led primarily by healthcare settings, the second by leisure/entertainment and the third by workplaces followed by educational-, healthcare- and non-work-associated settings. The trajectory for outbreaks was equally distributed amongst essential workplaces, non-essential workplaces, K-12 settings and non-essential healthcare settings.

Non-acute healthcare (19%; n=595), essential workplace (excluding healthcare) (18%; n=564) and non-essential workplaces (17%; n=536) experienced more outbreaks as compared to K-12 education (11%), entertainment (10%), large group living (5%), preschool education (5%), adult education (2%) and social gatherings (2%).

K-12 schools experienced 11% of all identified outbreaks, yet involved just 4% of total cases. Conversely, adult education outbreaks had disproportionately more cases - comprising 2% of all outbreaks but 9% of all cases.

Conclusion: Our findings suggest child educational settings were not the key driver of the latest wave in COVID-19 infections although they were contributors. Re-opening of schools coincided with parents returning to work and resumption of social activities. This may have accounted for the parallel rise in outbreaks in those settings suggesting contact points outside of school are more likely to seed in-school outbreaks than contact points within school as the wave of outbreaks in all other settings occurred either prior to or simultaneously with the wave in K-12 settings and pre-school.

Opening of schools is a priority but requires mitigation measures in order to do so safely including staggering the opening of different settings, continuing to 'work from home' wherever possible, and maintaining low levels of community transmission especially during the process of lifting NPIs.

INTRODUCTION

Globally policymakers are trying to balance difficult decisions about the mix of public health measures required to both contain the spread of COVID-19 cases whilst at the same time minimising wider social, wellbeing, educational and economic impacts. The COVID-19 pandemic has significantly disrupted education globally with almost universal impact on learners and teachers around the world. By April 2021 over 1.6 billion learners, from pre-primary to higher education, were affected in more than 190 countries and a recent UNICEF report (March 2021) found that for more than 168 million children globally schools have been closed for almost a full year [1].

Closure of educational establishments and a move, wherever feasible, to remote learning was one of the first non-pharmaceutical measures implemented in the majority of countries globally [2]. School closure as a non-pharmaceutical measure has been studied via modelling studies, epidemiological studies and in work focussing on economic, social, ethical and public health features of the policy [3][4][5][6][7][8]. However, the impact of school closures and reopening on transmission of SARS-CoV-2 in the wider community remains contested.

Whilst schools are recognised as settings where disease transmission can occur, there is a mismatch between the impact of COVID-19 itself on children and the impact of the response measures to the virus on children.

School closure is not a long-term solution especially in a pandemic with no clear end in sight. There is therefore an urgent need to understand how, and when, to reopen schools safely. We set out to analyse data on resolved outbreaks from Colorado, USA, along with a dataset of implemented public health measures in Colorado, in order to gain insights on the role of settings, and specifically educational institutions, on transmission plus the relationship between settings and the impacts of policies implemented.

METHODS

Data for the analysis were obtained from multiple sources. Outbreak data were obtained from the open access Colorado state outbreaks database [9][10]. This included both resolved and unresolved outbreaks identified in Colorado state from January 1st to December 31st 2020 inclusive. Data recorded included COVID-19 setting type, Colorado county, data that the cases were determined to be an outbreak, total staff cases, total cases and total deaths. Data on weekly overall deaths and COVID-19 deaths was obtained from the Colorado Department of Public Health and Environment.

A 'confirmed case of COVID-19' in the state of Colorado was defined as a case in a person who tested positive for SARS-CoV-2 virus using a molecular amplification detection test (such as PCR). The general definition of a 'confirmed COVID-19 outbreak' used in the state of Colorado required two or more individuals to have tested positive for SARS-CoV-2 infection, within a 14-day time period in a non-household group.

For healthcare settings, correctional settings and schools, the definition of an outbreak depended on the setting. In healthcare settings, the definition of an outbreak was 'two or more confirmed COVID-19 cases in residents with onset in a 14 day period. In correctional settings, including state prisons, county and city jails, community corrections, detention settings and work release facilities, the was two or more confirmed COVID-19 cases in residents/inmates/detainees with onset in a 14-day period. For schools, the definition was two or more confirmed COVID-19 cases among students/teachers/staff from separate households with onset within 14 days in a single classroom/cohort activity OR with evidence of transmission in the school setting (including transportation to- or from- school and affiliated events), or one confirmed case and two probable cases of COVID-19 among students/teachers/staff from separate households with onset within 14 days in a single classroom/cohort/activity OR with evidence of transmission in the school setting (including transportation to- or from- school and affiliated events).

Data on outbreak settings was grouped into six categories: education; entertainment and leisure; healthcare facilities; large group living; social gatherings and workplaces. These were then broken down further into 39 subcategories. Settings were also classified into two groupings, essential or non-essential, primarily dependent on whether the setting was required to close during the first lockdown. For educational settings, these were subcategorised and analysed as pre-schools, K-12 and adult education settings. For healthcare facilities, settings were grouped into acute and non-acute, and then subcategorised. A further assumption was made regarding whether the setting was considered indoor or outdoor (Supplementary materials table 1).

The data were analysed using Microsoft excel Version 16.4. Workplace setting was used as a benchmark comparator. The results were descriptively summarized. Epidemic curves were used to show trends over time.

Data on policy measures implemented in the state of Colorado were collated through review of press releases and public health orders from the Colorado Department of Public Health and Environment (CDPHE) website, and through screening of Executive Orders from the Colorado Governor. Substantive policy changes such as workplace or school closures, restrictions on workplace capacity, business openings, or changes to policy allowing people to socialise, were noted. Policies that were not considered substantive included temporary changes to regulations, and Executive Orders such as those relating to funding or taxpayer filing requirements. For schools we undertook a search to ascertain closure and reopening dates for the five most populous counties via county and school district websites and twitter accounts though primarily we relied on data obtained via public health orders and Executive Orders from the Governor (Supplementary materials table 2).

RESULTS

Between March 1st and December 31st 2020, there were 3,169 outbreaks (2,216 resolved and 953 unresolved) of SARS-CoV-2 involving 61,650 individuals. At least 96% of all identified outbreaks were associated with indoor environments. 60% of all outbreaks were registered in the six most populous counties (Denver, El Paso, Arapahoe, Jefferson, Adams and Larimer). Whilst two counties experienced no identified outbreaks, fifteen counties experienced more than 100 identified outbreaks per 100,000 population. These were all counties with small populations (<31,000) (Supplementary materials figure 1).

Workplaces, excluding educational settings and healthcare settings, were identified as the setting with the highest number of outbreaks followed by healthcare facilities (Table 1; Supplementary materials figure 2). The total number of cases associated with outbreaks were, however, largest in large group living settings and in-patient healthcare facilities indicating that the median size of outbreak tended to be larger in settings where people spent a prolonged duration of time together (Table 1; Supplementary materials figure 3).

Table 1. Documented settings associated with SARS-CoV-2 transmission outbreaks (n=3169)

Variation over time

In 2020, there were three waves of outbreaks. The first was led primarily by healthcare-associated outbreaks (118 outbreaks in April), in both acute and non-acute settings (including assisted living facilities such as elderly care homes) and workplaces (66 outbreaks in May). Workplace outbreaks were mostly in settings considered essential (e.g. manufacturing, construction and distribution). Workplace outbreaks reduced after May though there continued to be 1-2 outbreaks on average daily until the second wave. In July, over the summer break there was a small second wave of outbreaks. This was primarily due to an increase in outbreaks associated with entertainment/leisure that affected predominantly staff working in those settings (97% in dining facilities, 83% in bars/clubs, 69% in community spaces and 68% in sports/fitness).

The third wave began in mid-August, led by an increase of outbreaks in workplaces, educational-, healthcare- and non-work/leisure-associated settings (Figure 1). Affected workplaces included both non-essential and essential workplaces (Supplementary materials figure 4). K-12 schools did not open until August 24, 2020 and there was a phased return. Different counties operated different models such as cohorting, continuing remotely, hybrid, or in-school provision. Most counties wherever possible prioritised the return of elementary school children to in-school teaching first with younger years taking priority. In counties where ventilation improvements had been possible, high schools started reopening from September 14th. By October 19, all elementary schools were open. However, several counties switched to remote learning as the number of school outbreaks rose the following week (n=43). By November 13th only 44% of elementary schools and 22% of middle and high school were delivering in-school teaching. On November 17th, new workplace restrictions were announced. All high schools were requested to return to remote learning, and middle schools to implement remote or hybrid models of learning. Pre-schools and elementary schools were urged to remain open and plans were outlined for additional funding for outdoor classrooms, testing and protective equipment. This decision coincided with the peak of the second wave. After Thanksgiving break (November 21) all schools had switched to remote learning and this was maintained until the end of the year.

During the third wave, outbreaks in entertainment/leisure settings and healthcare facilities followed a similar trajectory as educational settings (Figure 1). In healthcare facilities, outbreaks were mostly in non-acute settings, primarily outpatients and assisted living facilities, whilst those in entertainment/leisure settings were primarily in dining facilities followed by sports related activities. Figure 2 details the epidemic curve for identified outbreaks by setting and includes a policy timeline.

Figure 1. Outbreaks reported in Colorado state by setting in 2020 including mortality data (approximately here)

Figure 2. Epidemic curve detailing outbreaks by setting type in Colorado state during 2020 including policy timeline (approximately here)

Educational facilities

Educational settings were associated with 18% (n=585) of all identified outbreaks and accounted for 14% (n=8,988) of cases (1,628 staff and 7,360 pupils). The trends in outbreaks in educational settings during this period are shown in Supplementary figure 5. 11% (n=360) of all outbreaks identified were in K-12 schools (for children aged 5-18 years). K-12 schools accounted for 62% of all outbreaks in educational settings. There was one death associated with the identified outbreaks in educational settings involving a member of staff in a preschool outbreak where 6 staff and 11 pre-school children were infected.

There were a number of differences found between child and adult education including the number and size of outbreaks as well as the impact on staff. There were ten times as many outbreaks identified in child, as compared to adult, education settings however there were half the number of total cases involved indicating that the median size of outbreak in adult educational settings was significantly greater than that in a child educational setting (Table 1; Supplementary figure 2 and 3).

Of the resolved outbreaks (n=468), there were 117 outbreaks (20%) where no staff cases were identified and 117 outbreaks (20%) where no pupil cases were identified. For preschool outbreaks there were more outbreaks involving staff than pupils (Supplementary figure 6). For K-12 children there were more outbreaks involving staff than pupils initially between August to October, but by November more outbreaks involved pupils than staff. In adult education, there were more outbreaks involving pupils than staff (Supplementary figure 6). Overall 84% of outbreaks in child education settings involved staff and the overall staff:pupil ratio was 1:1 whilst in adult education settings only 37% of outbreaks involved staff and staff:pupil ratio was 1:18 (Table 2). There were a further 17 outbreaks identified which were within school administration (n= 80 cases). These were primarily transportation or administration offices and all except three outbreaks involved non-teaching staff only. The three outbreaks involving pupils involved the transport service (11 staff and 8 pupils).

Table 2. Data on numbers of outbreaks, total cases and ratio of staff : non-staff cases (2020) (approximately here)

Workplaces

93% of all outbreaks involved at least one member of staff and staff accounted for nearly half (49%; n=28,455) of all cases associated with an outbreak (Table 1; Table 2). The number of cases per outbreak ranged from 2-294 individuals (median 4). Essential workplace settings on average experienced two waves over the year whilst non-essential workplaces experienced one wave that was slightly larger in volume and overlaid the second wave in essential workplaces (Supplementary materials figure 4). There were 57 staff deaths reported due to COVID-19 (46 in essential workplace settings and 11 in non-essential workplace settings) (Table 1).

Just over half of outbreaks (51%; n=1,596) involving 45,254 staff occurred in essential workplaces that were not required to close during 2020. The number of cases involved ranged from 2-294 (median=10). Twelve outbreaks involved more than 100 cases. These were in prisons (n=5), healthcare facilities (2 acute, 1 non-acute), manufacturing (n=3) and supply (n=1). Essential workplace outbreaks involving staff were mostly associated with healthcare (36% non-acute; 19% acute), manufacturing (9%), construction (8%) and prisons (6%).

Under half of outbreaks (49%; n=1,346) involving 7,600 staff occurred in workplaces classified as non-essential. These facilities were required to close in March and then were asked to comply with various restrictive measures as detailed in supplementary table 2. The number of cases involved ranged from 2-175 (median=3). Non-essential workplace outbreaks were mostly associated with K-12 education (21%), offices (18%), dining (17%) and retail (16%).

Number and size of outbreaks

The numbers of outbreaks that occurred between August and December in K-12 educational settings (11%; n=360) were similar to that in acute healthcare settings (10%; n=312) and leisure/entertainment facilities (10%; n=327) between March and December. Compared to educational settings, non-acute healthcare settings (19%; n=595), essential workplace settings (excluding healthcare settings) (18%; n=564) and non-essential workplaces (17%; n=536) experienced far more outbreaks whilst K-12 education (11%), entertainment large group living (5%), preschool education (5%), adult education (2%) and social gatherings (2%) experienced far fewer outbreaks. Whilst K-12 schools experienced 11% of all identified outbreaks, they involved just 4% of cases associated with an outbreak. Conversely, adult education outbreaks had disproportionately more cases - they comprised 2% of all outbreaks but 9% of all cases. Almost two-thirds of all cases, from August to December, were identified with large group living (25%; n=15,268) and healthcare facilities (acute 22%, n=13,735; non-acute 17%, n=10,251) (table 2).

DISCUSSION

Our findings suggest that child educational settings were not the key driver of the latest wave in COVID-19 infections although they were contributors. Infection in schools mirrored transmission and outbreaks in the community. The trajectory for outbreaks was equally distributed amongst essential workplaces, non-essential workplaces, K-12 settings and non-essential healthcare settings. It may be that the re-opening of schools coincided with parents returning to work which may have accounted for the parallel rise in outbreaks in those non-educational settings. Household transmissions might be the conduit linking educational, work and leisure settings. Similar to Li et al, we also observed a temporal association between the introduction and lifting of non-pharmaceutical interventions with outbreak reporting [11]. However, the delay was longer when introducing NPIs than when lifting them. This is likely because the date used to record an outbreak was the date of determination of an outbreak in that setting. Consequently, virus transmission from the index case will have already occurred prior to that date.

Educational establishments are a critical part of the community providing an integral connection between home, different work sectors and leisure (both adult and children activities). Conventional educational settings involve large numbers of people congregating at close quarters. With in-person schooling there are inevitably increased contact points, not only at school between pupils and between pupils and staff, but also between staff and between parents and carers. As children return to school, parents and carers are able to then return to work as well as resume social activities. All of these provide increased opportunity for virus transmission. Our findings suggest that these contact points outside of school are more likely to seed in-school outbreaks than those contact points within school as the wave of outbreaks in all other settings occurred either prior to or simultaneously with the wave in K-12 settings and pre-school.

The role that children and young people play in transmission is dependent on multiple factors such as their risk of exposure, susceptibility, extent of symptoms, extent to which their viral load rises and thereafter transmit, plus their social contacts and behaviour [12]. Many early studies exploring the role of children and young people were undertaken when children were not in school, their behaviours were constrained and hence and their exposure was minimal. Hence, it was difficult to ascertain the risk posed both to, and by, children [12][13][14][15][16]. Moreover, earlier studies of household transmission only tested symptomatic individuals and will likely have missed infected children who we know now are more likely to have milder or no symptoms [17][18][19]. Some recent studies have reported when children attended school and were interacting socially to some degree they were at risk of being infected [19][20][21][22]. However, younger children (1-10y) have been shown to have lower SARS-CoV-2 seroprevalence compared to their parents demonstrating they have lower rates of infection than adults [19][23]. In addition both younger and older children appear to be 6-15 times less likely to be hospitalised and 10-130 times less likely to die than adults aged 18-49 years [24].

This study has limitations. As an ecological study, causation cannot be confirmed from the associations found. Although our findings demonstrate that children were at risk of exposure in school, were susceptible to infection and that transmission does occur in educational settings, as reported elsewhere [25], the direction of transmission (adult-to-adult, child-to-child, adult-to-child or child-to-adult) could not be conclusively ascertained. An outbreak determination does not necessarily mean all cases were infected in the specified setting, and the case may have been exposed elsewhere. The CDPHE were explicit about this limitation stating

that if a case spent time in a specific setting with a known outbreak within the 14 day time period then illness was attributed to that outbreak even if there was no definitive proof that the case acquired their illness there [26]. As travel and contact histories were self-reported, they were prone to recall bias. Respondents may have their own views as to what constitutes a risky setting and may not mention common settings such as their homes or that of someone else. Additionally, the definition used for outbreaks in Colorado excludes household clusters. Consequently, no outbreaks were linked with households. However, this does not mean there was none. Indeed, households are recognized as settings where the risk of transmission is highest [27][28]. The epidemic trends, nearly equal proportions of outbreaks in workplace and educational settings, plus the mirroring of outbreaks in both settings suggest that household transmission is a likely conduit.

There are negative impacts of prolonged school closures on child health and wellbeing, as well as on the economy [29][30]. The opening of schools is a priority but requires mitigation measures during the pandemic in order to do so safely. These include staggering the opening of different settings whilst prioritising educational settings and maintaining low levels of community transmission especially during the process of lifting NPIs. Whilst in-person schooling allows parents the opportunity to return to work, close social contact should be minimised wherever possible. This may be through adults continuing wherever possible to 'work from home'. Schools can also reduce the risk of transmission through mask wearing, social distancing, hand hygiene and improving indoor air quality in classroom spaces [31][32][33][34]. Studies in other US states have shown that with appropriate risk mitigation measures, infections could be controlled even with high levels of circulating SARS-CoV-2 virus [35][36][37].

Whilst educational settings are unlikely to be the main driver for community spread of SARS-CoV-2 infection, society may subjectively perceive transmission risks linked to school settings to be greater than it is. The extent of in-schooling may be seen by some as a measure of how safe their community is. When the lifting of lockdowns are considered, clear public health communication will be required to stress that the return to in-person schooling does not equate to an immediate return to pre-COVID-19 normality. Furthermore, a concern going forwards is the threat of new variants. For example, the B.1.1.7 variant is reported to be more transmissible in both children and adults, and has spread to at least 114 countries worldwide [38]. By April 2021, more than 98% of cases in the UK were due to this variant and it was associated with a surge in both cases and deaths. Similarly, Germany by February 2021 the prevalence of virus variants (in particular, B.1.1.7) had risen to 70% in school-age children with positive PCR infections [19]. The risk of infection spread and emergence of infectious variants highlights the need for ongoing vigilance and mitigation measures in all settings including schools and workplaces.

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Figure 1. Outbreaks reported in Colorado state by setting in 2020 including mortality data.

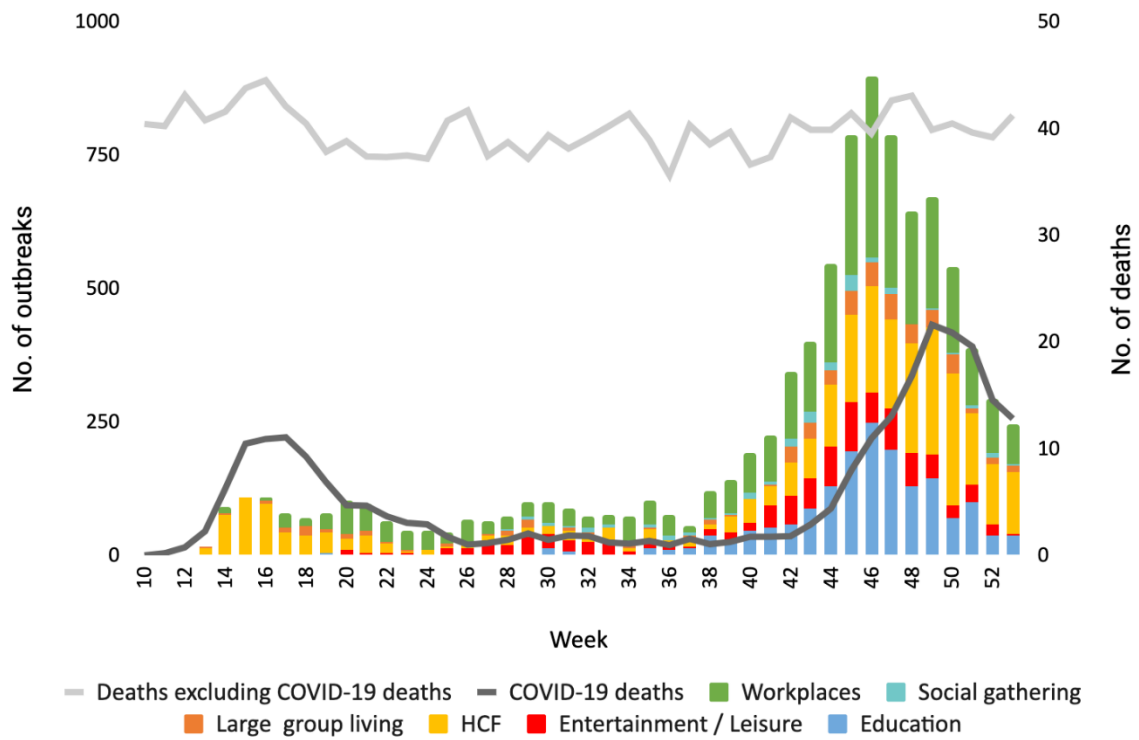


Figure 2. Epidemic curve detailing outbreaks by setting type in Colorado state during 2020 including policy timeline (*settings are stacked)

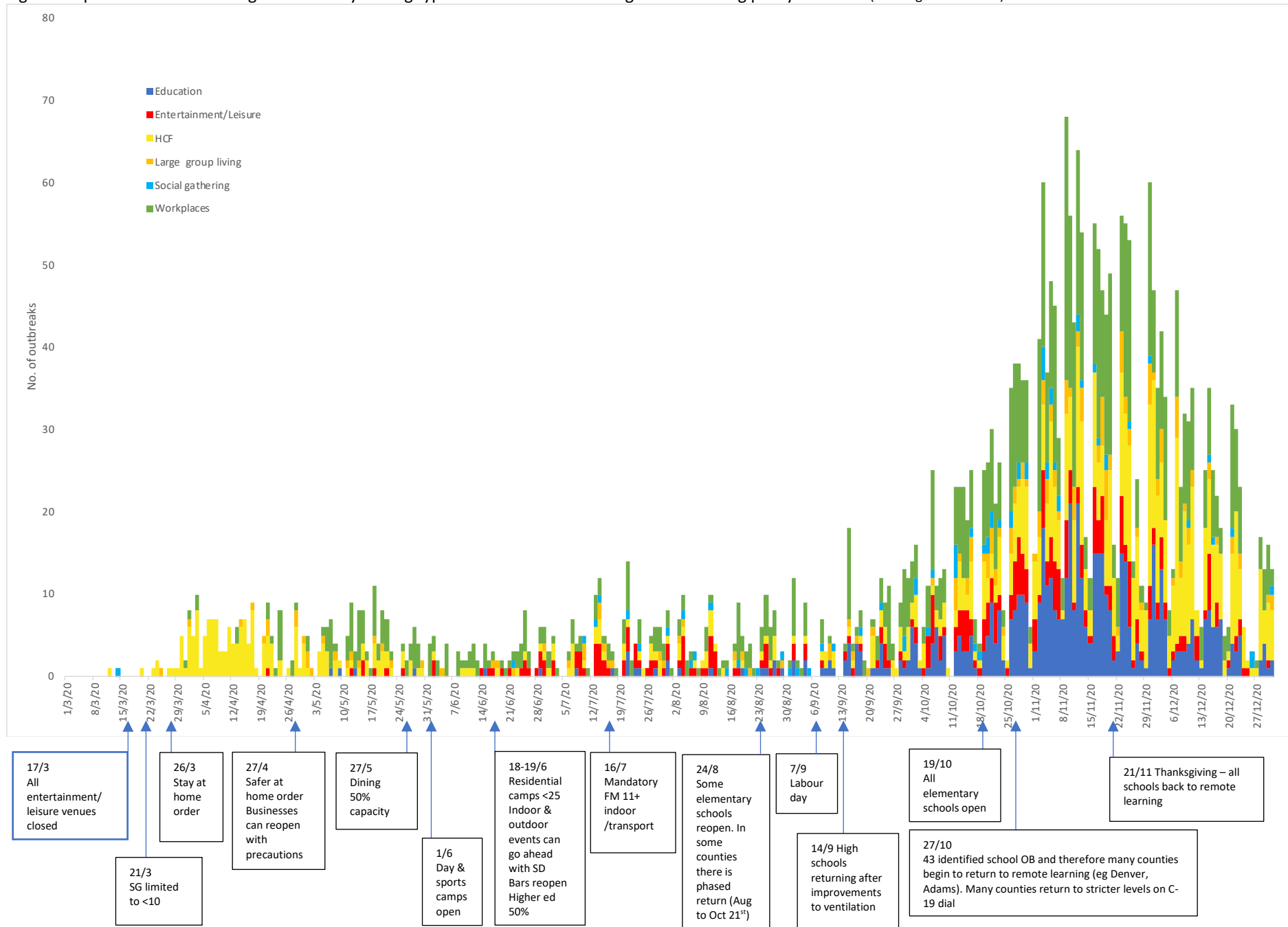


Table 1. Documented settings associated with SARS-CoV-2 transmission outbreaks (n=3169)

Setting type	Setting details		No. reported events	% total reported events	Total cluster size			Total no. of cases	Total no. of deaths	Total no. staff
					min	median	max			
Workplace (n=1100 excl healthcare and education; 35%)	Essential (n=564; 18%)	Manufacturing/factory/bakery/dairy/ farm	143	5%	2	8	294	2561	24	2519
		Construction	125	4%	2	4	96	1077	1	1070
		Shopping/supermarket	66	2%	2	7	71	735	2	735
		Distribution/storage	64	2%	2	9	96	825	6	825
		Emergency services/Law enforcement/env lab/cemetary	64	2%	2	5	78	475	0	465
		Animal clinic	26	1%	2	4	27	149	0	149
		Suppliers	23	1%	2	7	147	373	0	373
		Utilities	22	1%	2	4	25	135	0	135
		Transport	16	1%	2	14	86	333	0	333
		Mechanic/garage	9	0%	2	4	10	44	0	44
		Farm/Dairy	2	0%	2	4	5	7	0	7
	Mining	2	0%	3	20	37	40	1	40	
	Call centre	2	0%	4	5	5	9	0	9	
	Non-essential (n=536; 17%)	Offices	245	8%	2	4	175	1601	2	1591
		Retail/Car dealership/car rental	213	7%	2	5	91	1883	5	1881
		Personal services	44	1%	2	4	15	203	2	202
		School administration (transport/warehouse)	17	1%	2	4	12	80	0	72
Outdoor entertainment		9	0%	2	3	13	38	0	38	
Other - Art studio, catering, library, museum, security, visitors centre		8	0%	2	4	11	38	0	38	
Healthcare facility (n=907; 29%)	Acute (overall) (n=312; 10%)	Skilled nursing	284	9%	2	33	184	13466	1395	6334
		Acute care hospital	27	1%	2	8	24	267	3	251
		Long term acute care	1	0%	2	2	2	2	0	0
	Acute (staff) (n=306; 10%)	Skilled nursing	278	9%	1	17	112	6334	5	
		Acute care hospital	27	1%	2	8	24	251	0	
		Long term acute care	0	0%	0	0	0	0	0	
	Acute (patients) (n=280; 9%)	Skilled nursing	275	9%	1	15	106	7150	1390	
		Acute care hospital	4	0%	1	3	10	16	3	
		Long term acute care	1	0%	2	2	2	2	0	
	Non-acute (overall) (n=595; 19%)	Large group living*	439	14%	2	12	208	9195	696	4217
		Outpatient	146	5%	2	3	40	820	1	772
		Other**	10	0%	2	16	57	226	30	129
Non-acute (staff) (n=572; 18%)	Large group living*	416	13%	1	6	160	4217	6		
	Outpatient	146	5%	1	3	40	772	0		
	Other**	10	0%	2	11	28	129	0		

	Non-acute (patients) (n=433; 14%)	Large group living Outpatient Other**	413 13 7	13% 0% 0%	1 1 3	7 2 10	97 10 30	4978 48 97	690 1 30	
Educational facility (n=585; 18%)	Overall	Childcare School K-12, college/uni, trade school, first responder class	174 360 51	5% 11% 2%	2 2 2	4 4 8	28 48 2688	922 2255 5811	1 0 0	583 741 304
	Staff (n=468; 15%)	Childcare School K-12 college/uni, tradeschool	167 282 19	5% 9% 1%	1 1 1	3 2 3	20 12 157	583 741 304	1 0 0	
	Students (n=468; 15%)	Childcare School K12 college/uni, tradeschool	132 289 47	4% 9% 1%	1 1 1	2 3 9	11 46 2531	339 1514 5507	0 0 0	
Leisure/ Entertainment (n=327; 10%)		Dining	232	7%	2	4	94	1296	0	1263 (97%)
		Sports – fitness, bowling, golf, team sports	55	2%	2	4	54	431	0	299 (69%)
		Bar, casino, club, nightclub	36	1%	2	5	47	308	0	256 (83%)
		Community centre	4	0%	2	3	6	13	0	9 (69%)
Large group living (n=174; 5%)		Prison	102	3%	2	26	1616	14173	29 (0 staff)	1998 (14%)
		Hotel, resort	38	1%	2	4	64	289	1 (1 staff)	283 (98%)
		Employee housing	4	0%	3	5	7	20	0	7 (35%)
		Homeless shelter	18	1%	3	14	272	709	1 (0 staff)	144 (20%)
		Overnight school camp/dorm	6	0%	4	8	28	61	0	32 (52%)
		Apartment complex	4	0%	3	4	16	16	0	16 (100%)
Social gatherings (n=76; 2%)		Religious	41	1%	2	6	154	500	2 (0 staff)	290 (58%)
		Party, festival, youth gathering	26	1%	2	6	16	172	0	0 (0%)
		Wedding	6	0%	3	8	17	50	0	1 (2%)
		Bridge tournament	2	0%	8	16	24	32	4 (0 staff)	0 (0%)
		Work trip	1	0%	10	10	10	10	0	10 (100%)

*= Assisted living, Alcohol/drug abuse treatment (IP), Combined care, Facility for developmentally disabled (IP), Group home, Hospice, Independent living facility, Psychiatric hospital, Rehab facility

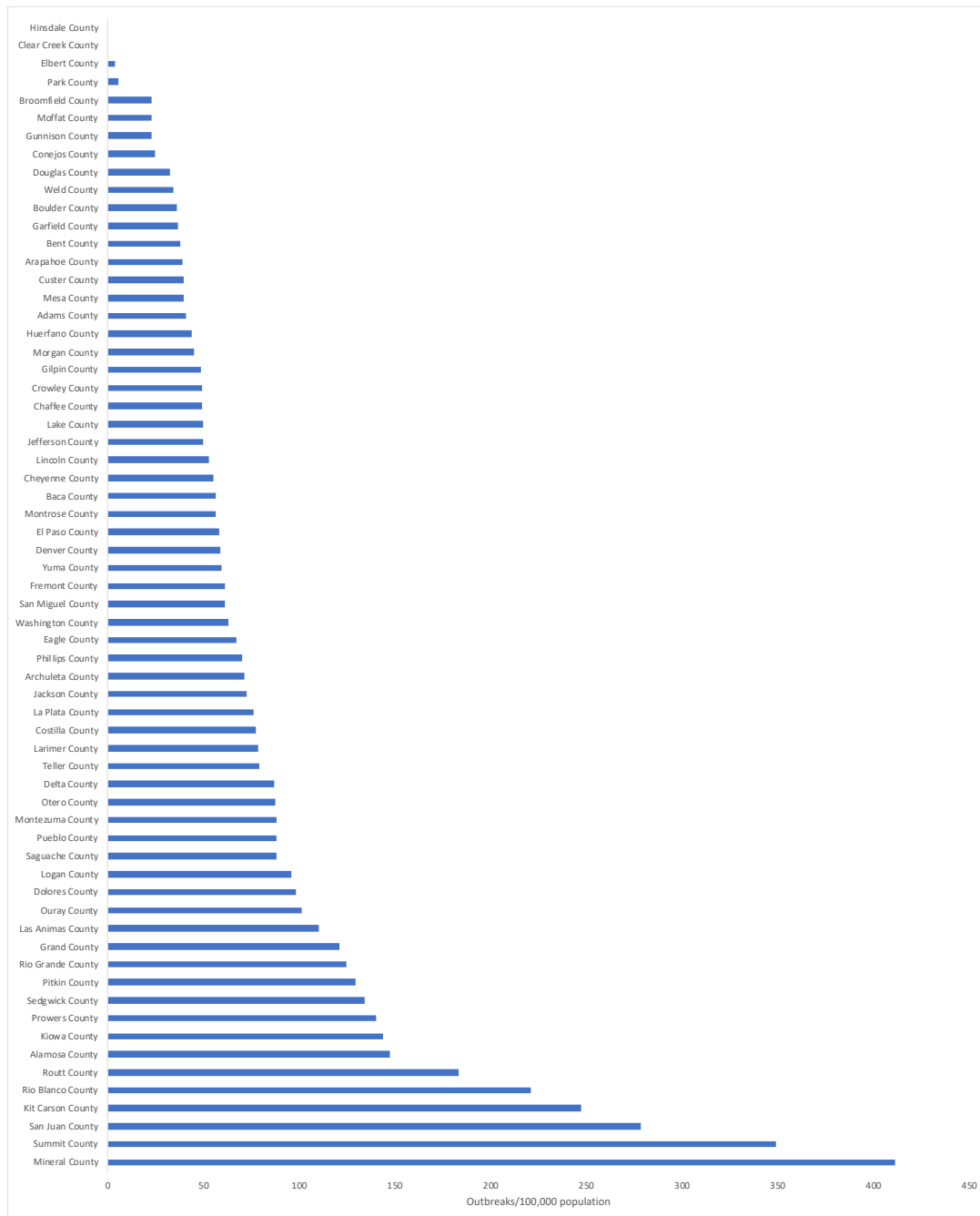
** = ambulatory surgery, memory centre

Table 2. Data on numbers of outbreaks, total cases and ratio of staff : non-staff cases (2020)

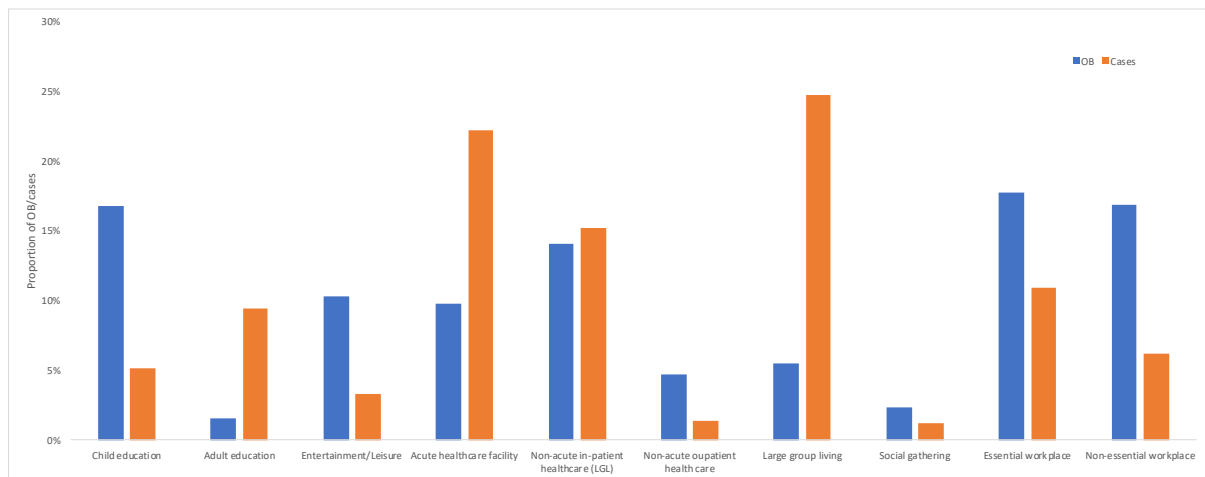
Setting	No. OB total	No. total cases	No. cases Staff : non-staff	Ratio cases Staff: non-staff	No. OB involving staff [no. (%)]
Education:					
Child	534	3177	1324: 1853	1 : 1	449 (84%)
Adult	51	5811	304: 5507	1:18	19 (37%)
Entertainment/ Leisure	327	2048	1827: 221	8 : 1	317 (97%)
Healthcare					877 (97%)
Acute	312	13735	6585: 7150	1 : 1	
Non-acute	593	10,241	5118: 5123	1 : 1	
Large group living	174	15,268	2480: 12,788	1 : 5	159 (91%)
Social gathering	76	764	291: 473	1 : 2	31 (41%)
Workplace:					
Essential	564	6763	6704: 59	114 : 1	564 (100%)
Non-essential	536	3843	3822:21	182 : 1	534 (99.6%)
Overall	3169	61,650	28,455: 33,195	1 : 1	2950 (93%)

Supplementary material

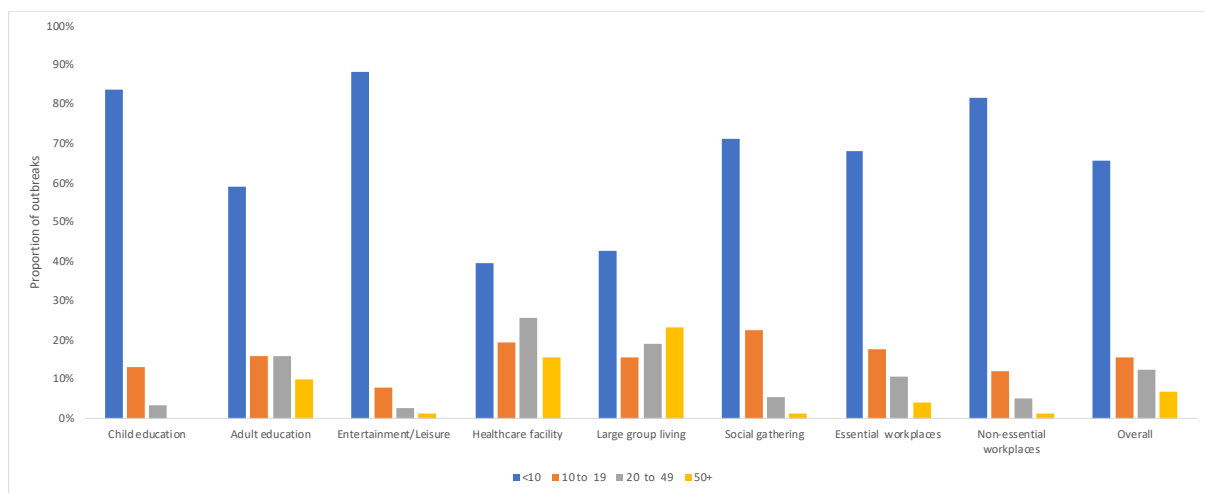
Supplementary figure 1. Outbreaks/100,000 population experienced in 2020 by county in Colorado



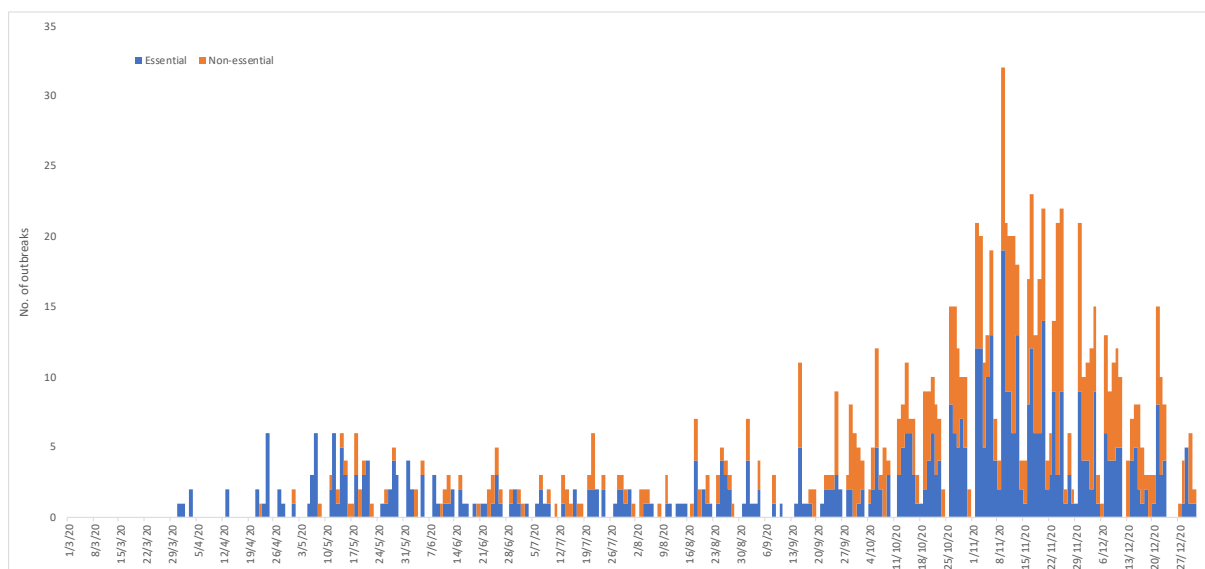
Supplementary figure 2. Identified outbreaks by settings (2020)



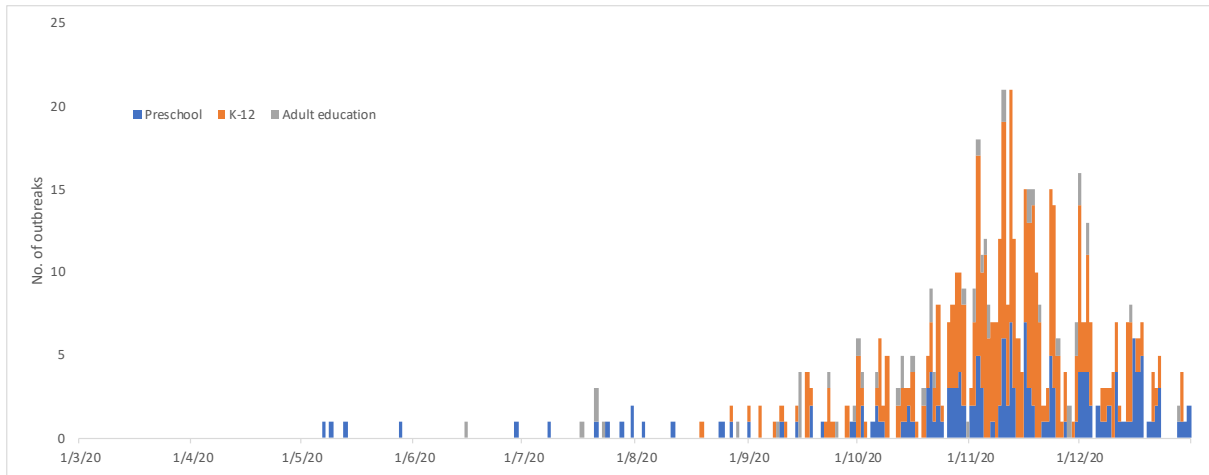
Supplementary figure 3. Size of outbreaks associated with settings (2020)



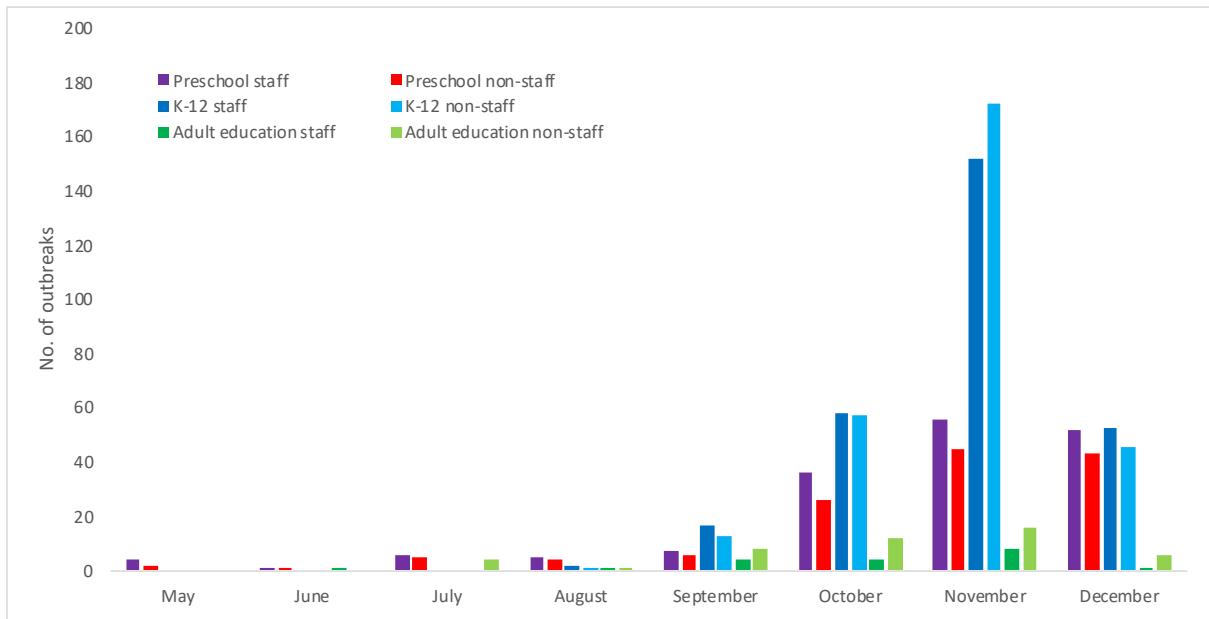
Supplementary figure 4. Epidemic curve for essential and non-essential workplaces (excluding staff in educational and healthcare facilities)



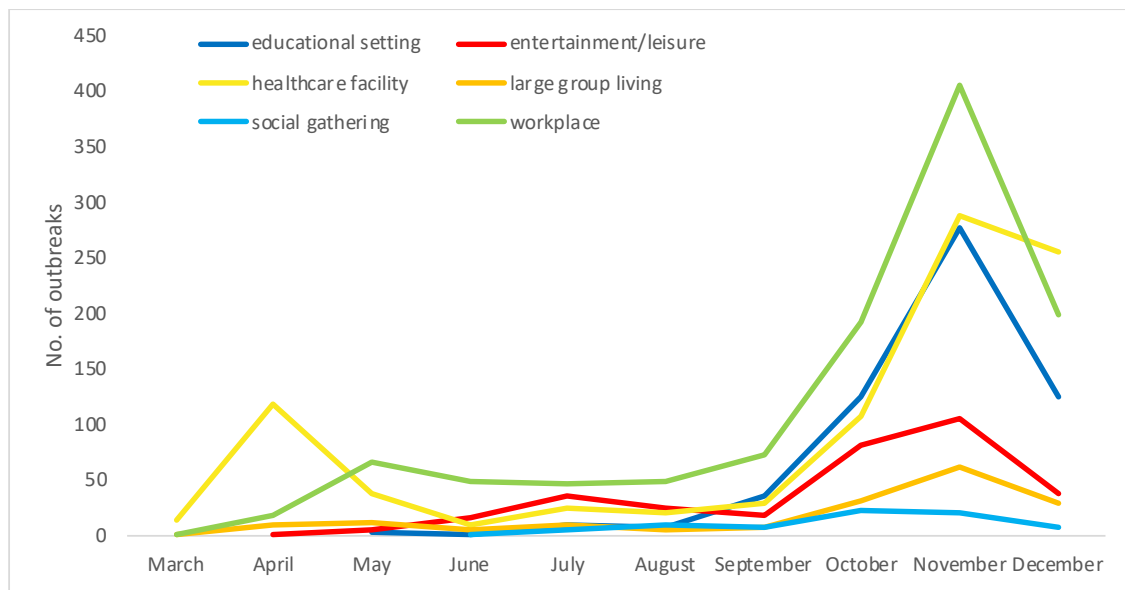
Supplementary figure 5. Stacked epidemic curve of outbreaks in educational settings in 2020



Supplementary figure 6. Outbreaks over time by educational facility and staff/pupil



Supplementary figure 7: Outbreaks reported monthly in Colorado state by setting in 2020



Supplementary table 1. Settings details and categories

Setting category	Setting subcategory	Essential/Non-essential	Indoor/Outdoor
Education	Pre-school	Non-essential	Indoor
	K-12/school	Non-essential	Indoor
	Adult education	Non-essential	Indoor
Entertainment/Leisure	Bar etc	Non-essential	Dependent on venue
	Community centre	Non-essential	Indoor
	Dining	Non-essential	Indoor (though if an outdoor site eg BBQ then classified as outdoor)
	Sports	Non-essential	Dependent on venue and type of sport
Healthcare facility	Acute skilled nursing	Essential	Indoor
	Acute care hospital	Essential	Indoor
	Acute Long term acute care	Essential	Indoor
	Non-acute large group living *	Essential	Indoor
	Non-acute outpatient	Essential	Indoor
	Non-acute other **		
Large group living	Apartment complex	Essential	Indoor
	Employee housing	Essential	Indoor
	Homeless shelter	Essential	Indoor
	Hotel/lodge/resort	Non-essential	Indoor
	Overnight camp/dormitory	Non-essential	Indoor (camping is a mix of indoor and outdoor)
	Prison	Essential	Indoor
	Treatment facility	Essential	Indoor
Social gathering	Bridge	Non-essential	Indoor
	Party	Non-essential	Indoor
	Religious	Non-essential	Indoor
	Wedding	Non-essential	Indoor
	Work trip	Non-essential	Indoor
Workplace	Animal clinic	Essential	Indoor
	Call centre	Essential	Indoor
	Construction	Essential	Outdoor
	Distribution	Essential	Indoor
	Emergency Services	Essential	Indoor
	Farm/Dairy	Essential	Both
	Garage	Essential	Indoor
	Manufacturing	Essential	Indoor
	Mining	Essential	Both
	Office	Non-essential	Indoor
	Other	Non-essential	Indoor
	Outdoor entertainment	Non-essential	Outdoor
	Personal services	Non-essential	Dependent on type of workplace
	Retail	Non-essential	Indoor
	School admin	Non-essential	Indoor
	Shopping/supermarket	Essential	Indoor
Suppliers	Essential	Indoor	
Transport	Essential	Indoor	
Utilities	Essential	Indoor	

* = Assisted living, Alcohol/drug abuse treatment (IP), Combined care, Facility for developmentally disabled (IP), Group home, Hospice, Independent living facility, Psychiatric hospital, Rehab facility

** = ambulatory surgery, memory centre

Supplementary table 2. Colorado timeline of COVID-19 public health policy measures implemented in 2020

Date effective	Policy change	Source	Details
11 March 2020	Disaster Emergency declared	Executive Order D 2020 003	
13 March 2020	Assisted living etc. visitors restricted.	https://covid19.colorado.gov/press-release/state-health-department-restricts-visitors-skilled-nursing-assisted-living-and	
14 March 2020	Ski resorts closed	Executive Order D2020 004	
15 March 2020	People who have been in affected locations advised to minimise contact with others.	https://covid19.colorado.gov/press-release/cdphe-strongly-advises-all-visitors-and-residents-eagle-summit-pitkin-and-gunnison	
15 March 2020	Recommends cancelling all events of 50+ people.	https://covid19.colorado.gov/press-release/cdphe-recommends-colorado-follow-cdc-guidance-cancel-or-postpone-person-events-50	
17 March 2020	Closure of bars, restaurants, gyms, casinos, theatres.	https://covid19.colorado.gov/press-release/state-health-department-issues-public-health-order-closing-colorado-bars-restaurants	Exceptions: Grocery stores, markets, convenience stores, pharmacies, drug stores, food pantries, room service in hotels, health care facilities, residential care facilities, congregate care facilities, juvenile justice facilities, crisis shelters or similar institutions, airport concessionaires, and any emergency facilities necessary for the response to these events. Takeaway food.
18 March 2020	Suspension of in-person schooling	Executive Order D 2020 007	Excepting approved facility schools
20 March 2020	In-person vital records services closed.	https://covid19.colorado.gov/press-release/state-health-department-closes-person-vital-record-services-phone-and-online-services	
21 March 2020	PHO on social distancing updated. Gatherings limited to 10 people or fewer.	Press Release 21 March 2020: State health department amends 'social distancing' public health order. Amended PHO 20-23	Exceptions: Essential goods and services, courts, public transport, delivery / takeaway food, homeless shelters, childcare, media offices, government offices, factories where social distancing in place.
22 March 2020	Employers ordered to reduce in-person workforce by 50%	Executive Order D 2020 013	CDPHE directed to issue a PHO identifying critical businesses etc.

24 March 2020	PHO reducing in-person work and increasing social distancing.	Press Release 23 March 2020 PHO 20-24	50% reduction in nonessential business in-person work. Social distancing increased to 6 feet and gathering no more than 10 people. This applies to all businesses, including critical, where possible.
26 March 2020	Stay-at-home order	https://covid19.colorado.gov/press-release/state-health-department-enacts-public-health-order-critical-measure-save-lives Executive Order D 2020 017 SECOND UPDATED PUBLIC HEALTH ORDER 20-24 IMPLEMENTING STAY AT HOME REQUIREMENTS	PHO 20-24 defines critical businesses and necessary activities which are exceptions to the stay-at-home order.
14 April 2020	Childcare for children of essential workforce	Executive Order D 2020 035	Emergency childcare collaborative created to provide care for children of essential workforce. Certain statutes suspended to facilitate.
21 April 2020	Long-term care facilities – PHO amended	https://covid19.colorado.gov/press-release/state-releases-amendment-to-public-health-order-for-long-term-care-facilities PHO 20-20 Amended.	Long-term care facilities must submit Covid-19 prevention and control plans by 1 May. Including severe limits on visitors. Residents and employees to wear facemask in public. Staff to be masked at all times in facility.
23 April 2020	Mask order. Mandatory masking for critical business employees while at work. All Coloradans REQUESTED to wear mask in public when outside home.	https://covid19.colorado.gov/press-release/state-releases-public-health-order-requiring-critical-business-employees-to-wear PHO 20-26 Face coverings for critical business Executive Order D 2020 029	Masking order for workers in critical businesses & critical govt functions. If working within 6 feet. Includes banks, childcare, pharmacies, grocery stores. Executive Order D 2020 044 Advises all Coloradans to wear face coverings in public.
26 April 2020	Safer At Home announcement. Stay-At-Home now advisory, not mandatory.	Executive Office Press Release – Safer At Home Executive Order D 2020 044 PRESS Release 27 April 2020 PHO 20-28 Safer At Home	Relaxation where Stay At Home is no longer ordered but advised. Businesses - more can open with precautions. Revises age for shielding upwards from 60 to 65. Gatherings of >10 prohibited. Introduced 3 levels - Stay At Home, Safer At Home, Protect Our Neighbours. Restaurants, bars, gyms, casinos to remain closed.

			Limited reopening of postsecondary education institutions allowed. Local governments can tighten or relax rules more than the State. Must seek variance order in certain circumstances.- see Appendix G of PHO 20-28 (Amended)
27 April 2020	Phase 1 of business relaxations. Curbside retail delivery Voluntary/elective medical procedures Veterinary surgeries	Executive Office Press Release – Safer At Home	Retail businesses can open for curbside delivery. Real estate home showings can resume. Voluntary or elective medical, dental, and veterinary surgeries and procedures may resume if facilities are following required safety protocols.
1 May 2020	Phase 2 – Retail & personal services re-opening	Executive Office Press Release – Safer At Home PHO 20-28 (Amended)	Retail can phase-in public opening, and personal services can open, if following best practices.
4 May 2020	Phase 3 – Offices & non-critical manufacturing reopening	Executive Office Press Release – Safer At Home PHO 20-28 (Amended)	Non-critical office-based businesses may allow employees to attend at 50% capacity. Non-critical manufacturing can reopen with no more than 10 employees in a production environment, subject to requirements. Childcare reopen or expand if following requirements.
25 May 2020	Private Campsites open Indoor sports allowed at limited capacity	https://covid19.colorado.gov/press-release/state-health-department-amends-safer-at-home-public-health-order-allowing-additional Fourth Amended PHO 20-28	Campsites open but group indoor facilities eg yurts, cabins, closed. Indoor sports allowed with <10 people per room.
27 May 2020	Restaurants open to in-person dining	Fourth Amended PHO 20-28 Appendix I	50% capacity or 50 people, whichever fewer. Tables limited to 8 people, 6 feet apart. May use any existing outdoor space with same group and spacing limits.
1 June 2020	Children's day and Sports camps open	Fourth Amended PHO 20-28 Appendix J	Subject to requirements. No residential.

4 June 2020	Places of Worship reopen	Fifth Amended PHO 20-28 section M	To the lesser of 50% capacity indoors / 50 people. 6 feet distancing between households. Face masks to be worn by everyone over age 2 / exemptions.
5 June 2020	Personal and Outdoor Recreation guidance issued: Safer At Home and In the Vast, Great Outdoors	Press Release 4 June 2020 Sixth Amended PHO 20-28 Executive Order D 2020 091	Activities that can be done in groups of 10 or fewer, with distancing & precautions eg hand washing and mask wearing allowed, unless explicitly prohibited in the PHO. Travel allowed as necessary to access outdoor recreation areas. Organized sports resume with up to 25 people outdoors or 10 indoors. Gyms and indoor pools open to 25% capacity / 50 people
18 June 2020	Residential camps reopen.	Press Release 19 June 2020 Seventh Amended PHO 20-28	Residential camps allowed with 25 or fewer outdoors, 10 or fewer indoors.
19 June 2020	Indoor and outdoor events can go ahead subject to distancing.	Press Release 19 June 2020 Seventh Amended PHO 20-28	
19 June 2020	Bars and restaurants reopen	Press Release 19 June 2020 Seventh Amended PHO 20-28	Can reopen and increase capacity subject to precautions.
19 June 2020	Higher Education in-person allowed	Press Release 19 June 2020 Seventh Amended PHO 20-28	Encouraged to continue remote learning but permits in-person up to 50% capacity / 50 people.
19 June 2020	Manufacturing can work up to 50% capacity per room / 50 people. Distancing & masking required.	Press Release 19 June 2020 Seventh Amended PHO 20-28	
24 June 2020	Residential care facilities allowed outdoor visits.	https://covid19.colorado.gov/press-release/state-health-department-releases-guidance-allowing-visitors-at-residential-care	
1 July 2020	Bars temporarily closed unless serving food, otherwise can sell takeaway alcohol only. Real estate open houses resume Libraries no longer limited to curbside delivery.	Press Release 1 July 2020 Eighth amended PHO 20-28	Bars serving food must meet requirements for restaurants. 50% capacity / 50 people or fewer in closed environments , 6 feet apart. Up to 100 people subject to calculations.
1 July 2020	Professional sports resume.	Press Release 1 July 2020 Eighth amended PHO 20-28	Can commence training/practice/league play once plans approved by CDPHE.

6 July 2020	Protect Our Neighbours roadmap Local communities gain more control if meet conditions.	Press Release 30 June 2020 Executive Order D 2020 127 PHO 20-32 10 July 2020	Local communities that have met certain qualifications and have a mitigation and containment plan in place can allow all activities to occur at 50% capacity with Social Distancing, up to 500 people in a setting.
17 July 2020	Mask Order	Press Release 16 July 2020 Executive Order D 2020 138	All individuals 11 years & older to wear a face covering when entering or moving within any public indoor space & While using or waiting to use public (buses, light-rail) or non-personal (taxis, car services, ride-shares) transportation services.
20 July 2020	Guidance released to prepare for school reopening.	https://covid19.colorado.gov/press-release/guidance-released-to-help-local-public-health-agencies-and-schools-navigate-opening	
21 July 2020	Alcohol sales to cease by 10pm	Executive Order D 2020 142	
August 2020	Schools start to reopen	In-Person Learning in the Time of Covid-19	Reopening dates varied by county, school district, and by school year, so no single date or week can be provided. However, most schools began to offer some in-person learning during August 2020. Some examples from the largest counties are included below.
7 August 2020	Definition of individuals at risk of severe illness from Covid-19 extended	Executive Order D 2020 154	Now includes: Age 65+, and people with cancer, chronic kidney disease, COPD, immunocompromise, BMI 30+, serious heart conditions, sickle cell disease, T2 Diabetes , or otherwise determined to be high risk by a healthcare practitioner. New conditions in bold.

			Removed: Pregnant women, people with chronic lung disease or moderate to severe asthma.
11 August 2020	schools guidance updated	Press Release 11 August 2020	
21 August 2020	Alcohol sales to cease by 11pm	Executive Order D 2020 170	
24 August 2020	Some elementary pupils return to school. El Paso Academy District 20 reopens for K-5	https://www.asd20.org/announcements/superintendent-newsletter-august-14-2020/	
3 Sept 2020	Residential care facilities allowed indoor visits.	press Release 3 Sept 2020	Subject to conditions, in areas of low incidence.
7 Sept 2020	Labor Day (public holiday)		
14 Sept 2020	More school pupils return eg Middle & High School pupils return for hybrid learning in El Paso Academy District 20 and in District 49 (Colorado Springs and El Paso County)	https://www.d11.org/Domain/5173 https://www.asd20.org/announcements/superintendent-newsletter-september-4-2020/ https://www.d49.org/site/Default.aspx?PageID=5447	Eg ASD20 High School pupils returned on 14 Sept using hybrid learning / cohorting model.
15 Sept 2020	DIAL framework (tiers) released.	press Release 15 Sept 2020 PHO 20-35 Safer At Home Dial 15 Sept 2020	Based on scientific metrics, as well as local control, the dial has five levels with associated guidances: <ol style="list-style-type: none"> 1. Protect Our Neighbors 2. Safer at Home 1- Cautious 3. Safer at Home 2- Concern 4. Safer at Home 3- High Risk 5. Stay at home

			<p>Counties move between levels based on these metrics:</p> <ol style="list-style-type: none">1. Number of new cases. The case count provides information on how prevalent the virus is circulating in communities.2. Percent positivity of COVID tests. The percent positivity is a clear indication if enough testing is being done.3. Impact on hospitalizations. Hospitalization data provides information about health care capacity. <p>To move to a less restrictive level (eg, Level 2 to Level 1), counties need to meet and sustain <u>all</u> three metrics for two weeks. Counties must engage in a consultation process with CDPHE, which may entail moving to a more restrictive level, when they are out of compliance with any of the metrics for more than two weeks.</p> <p>The dial replaces most variances. CDPHE will continue to consider applications for site-specific variances for unique facilities, stadiums, or other extra-large venues or events. Variance requests must conform to CDPHE requirements and be submitted by the local public health agency.</p>
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16 Sept 2020	Organized Sports guidance released	Press release 16 Sept 2020 Guidance for Organized Sports – 16 Sept 2020	To fit with DIAL framework, group size restrictions and best practice for each level. Eg Level 1 – groups of up to 50 players per court/field, Level 2 – up to 25, level 3 – up to 10.
21 Sept 2020	More schools returning eg Colorado Springs D11 Elementary & middle school pupils return	https://www.d11.org/Domain/5173	
5 Oct 2020	More High Schools returning to in-person learning eg D11	https://www.d11.org/Domain/5173	
8 Oct 2020	Alcohol sales last call tied to DIAL level.	Press release 8 Oct 2020	
13 Oct 2020	DIAL Capacity restrictions	Capacity restrictions table as at 13 Oct 2020	
19 Oct 2020	More High School pupils return to in-person eg Pueblo County D60 High Schools return to in-person for first time. Delta County returns .	KRDO news article 22 Oct 2020 Montrose Press: Delta County High Schools return.	Hybrid platform where half school alternates days in class. Elementary schools in D60 had returned in August.
19 Oct 2020	More elementary pupils return to in-person this week, eg Douglas County School District Denver public schools completed phased return of elementary pupils 21 Oct..	Douglas County welcomes elementary pupils back Denver Public Schools newsletter 27 Oct 2020	
20 Oct 2020	Most Colorado schoolchildren are back for in-person learning	Governor Polis Covid-19 Update 20 Oct 2020 48:03 onwards	“Schools are back across our state ..Across our state, the vast majority of districts are... back full-time at all levels, but there are some districts in the Metro area that are only partially back.”
23 Oct 2020	Personal gatherings limited to 10 people, 2 households for Safer At Home counties.	Press release 23 Oct 2020 DIAL Capacity restrictions table 23 Oct 2020	Some counties, such as Denver, Arapahoe, Adams, and Boulder, have recently instituted stricter public health orders on meeting sizes. Coloradans living in counties

			with stricter orders must follow those ordinances.
27 Oct 2020	Denver public schools re-close for most years	https://www.dpsk12.org/our-dps-weekly-october-27-2020/	
27 Oct 2020	Gym capacity increased for SAH L3	https://covid19.colorado.gov/press-release/state-updates-safer-at-home-public-health-order-provides-greater-flexibility-for-gyms	Minor change allowing gyms in SAH Level 3 county to operate at 25% capacity / up to 25 people.
27 Oct 2020	Several large counties move to stricter DIAL levels	https://covid19.colorado.gov/press-release/several-counties-moving-to-stricter-levels-on-colorados-covid-dial-to-protect-their Capacity restrictions for each level, by setting	Several counties moved levels, including: Adams County to Safer At Home (SAH) 3 Arapahoe to SAH 2 Denver County to SAH 3 Every Safer at Home level limits personal gatherings to 10 or fewer people from no more than two households, and there are various capacity limits for other activities.
29 Oct 2020	More counties move to stricter DIAL levels	Press Release 30 Oct 2020	Counties moving to stricter levels of DIAL including: Douglas County to SAH 2 El Paso County to SAH 2
2 Nov 2020	Updated DIAL guidance by colour	Press release 2 Nov 2020 PHO 20-36 Executive Order D 2020 235	Updates DIAL guidance to colour-coded warning systems. Some changes and clarifications.
2 Nov 2020	Transportation guidance	Press release 2 Nov 2020	Limit capacity to 50%, distance household groups. Masking for all aged over 10.
5 Nov 2020	More counties move to stricter DIAL levels	Press release 5 Nov 2020	Boulder, Broomfield, Mesa, Summit, Kit Carson and Jefferson counties to Orange level. Larimer to Yellow.

11 Nov 2020	Schools guidance on in-person learning	<p>In-Person Learning in the Time of Covid-19</p> <p>https://www.denverpost.com/2020/11/12/colorado-schools-covid-remote-learning-denver/</p> <p>[Archive copy: Denver Post 12 Nov 2020 How Schools are hosting classes]</p>	<p>PHO 20-36 clarifies that school districts are allowed to make decisions regarding in-person, hybrid, or virtual learning. Schools defined as critical businesses. Should prioritise in-person learning for younger & vulnerable pupils. Mitigation measures including cohorting and scheduling should be used to reduce the number who will need to quarantine after a case. Report suggests school mitigation measures working. Extracurricular activities should be restricted or eliminated.</p>
17 Nov 2020	<p>Governor states preferences for learning venues:</p> <p>K-5 in-person learning strongly encouraged</p> <p>Middle school - in-person, hybrid or remote</p> <p>High school – hybrid or remote</p> <p>Higher Education – remote</p>	<p>Jared Polis press conference 17 Nov 2020 , 8m 40s onwards</p> <p>Chalkbeat: Polis announces new restrictions but urges Colorado schools to stay open – 17 Nov 2020</p> <p>Denver Post article 19 Nov 2020</p>	<p>“For counties that fall under Level Red... we encourage preschools through 5th grade students to continue learning in person, or to restart if the districts have taken a hiatus. Middle school students can do in person or hybrid or remote, and in the highest-risk areas, high school students generally should be hybrid or remote and higher education should be generally online....</p> <p>We want to make sure we emphasise the need for K-5 especially to return to in-person instruction.”</p>

20 Nov 2020	Counties moving to stricter DIAL levels	Press release 17 Nov 2020 Press release 19 Nov 2020 https://www.denverpost.com/2020/11/17/colorado-covid-coronavirus-counties-level-red/ [archive copy]	<p>20 counties to Level Red – Severe Risk. Most indoor activities prohibited or strictly limited.</p> <p>9 to Orange.</p> <p>Level Red applies to 4 of the 5 most populous counties.</p>
20 Nov 2020	Updated DIAL framework	Press release 17 Nov 2020 DIAL restrictions table from 20 November 2020	<p>New highest level Purple ‘Extreme Risk’ added.</p> <p>Level Red relaxed slightly, no longer triggers ‘Stay At Home’ order.</p>
20 Nov 2020	Visitors inside residential care homes criteria	Press release 20 Nov 2020	<p>Some changes to criteria for visits.</p>
21 Nov 2020	Thanksgiving Break. Most schools switch to remote learning for rest of term.	https://co.chalkbeat.org/2020/11/18/21574116/denver-online-learning-after-thanksgiving Most of Colorado’s largest districts are now offering remote instruction – Chalkbeat, 4 Dec 2020	<p>Thanksgiving break 21-29 Nov. Most schools switch to remote learning after this for rest of term. eg Denver Public Schools, El Paso D20, Colorado Springs D11.</p> <p>“Most of Colorado’s students now must learn from home — a stark contrast to just weeks earlier.</p> <p>In November many school districts switched to entirely virtual learning. A Chalkbeat analysis of the 30 largest districts in the state shows 22 are now fully remote. Of the remaining eight that still provide some in-person instruction, only three offer it to students of all grade levels.”</p>
7 Dec 2020	Places of Worship / Educational institutions – more flexibility	Press release 7 Dec 2020	<p>Fairly minor. Places of worship classified as essential and can exceed capacity caps.</p>

			Institutions like museums, aquariums, zoos can open indoors for educational functions up to 25% capacity / 25 people.
4 Jan 2021	All Level Red counties move to Orange.	https://covid19.colorado.gov/press-release/red-level-counties-move-to-orange-level-effective-today	Counties can choose to operate with more restrictive guidance, but are only obliged to operate at Level Orange.
4 Jan 2021	5 Star Certification scheme launched	Press release 4 Jan 2021	Businesses can voluntarily exceed required safety measures and qualify for 5 Star State Certification, allowing them to operate with increased capacity.

