

INSTITUTIONAL RESPONSIBILITY AND CONNECTIVITY EFFICIENCY IN PUBLIC SCHOOLS DURING THE COVID-19 PANDEMIC: A COMPARATIVE ANALYSIS OF THE DIGITAL DIVIDE IN TUNJA, COLOMBIA (2020–2021)

ABSTRACT

The COVID-19 pandemic highlighted deep structural inequalities in educational connectivity across low- and middle-income countries. This study evaluated the relationship between socioeconomic vulnerability and internet access in 14 public schools in Tunja, Colombia, during the most critical stage of social isolation in 2020 and one year later. An institutional census design was combined with Pearson correlations, paired-samples t-tests, and clustered ordinary least squares regression to analyse school-level connectivity patterns. The mean school-level proportion of students without internet access decreased from 56.5% in 2020 to 32.5% in 2021, corresponding to a 24.0-percentage-point increase in average school-level connectivity (95% CI: 10.7–37.2; $p = 0.0018$). A strong inverse association between the socioeconomic index and school-level connectivity was observed in both 2020 ($r = -0.804$, $p = 0.00053$) and 2021 ($r = -0.794$, $p = 0.00069$). Despite government efforts to distribute laptops and SIM cards, some of the most vulnerable institutions, particularly rural and peri-urban schools, showed limited improvement or even deterioration in connectivity. The findings suggest that expanding connectivity is necessary but may be insufficient to achieve educational equity. Digitally inclusive policies should therefore be territorially sensitive and pedagogically grounded if they are to address structural educational inequalities.

KEYWORDS

COVID-19, education, efficiency, technology adoptions

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Highlights

- Average school-level internet connectivity increased by 24.0 percentage points between 2020 and 2021 across public schools in Tunja.
- Socioeconomic vulnerability was strongly and inversely associated with school connectivity in both 2020 and 2021.
- Connectivity gains remained uneven, with rural and highly vulnerable schools continuing to experience substantial digital-access gaps.
- Providing laptops and SIM cards alone did not consistently translate into greater connectivity, highlighting the need for territorially sensitive digital-inclusion policies.

INTRODUCTION

The COVID-19 pandemic and the lockdown measures adopted by governments exposed widespread inequalities across multiple sectors of society, with education among

the most severely affected. Worldwide, schools were closed for an average of nearly 95 school days between March 2020 and February 2021, leaving more than 1.6 billion students without access to in-person education and exacerbating

learning gaps, particularly among vulnerable populations lacking adequate connectivity or digital resources. Before the pandemic, approximately 59% of the global population had internet access. By 2021, this figure had risen to around 61%, equivalent to almost 4.8 billion users worldwide, reflecting the rapid expansion of global connectivity from a penetration rate of only 17% in 2005 to more than 53% in 2019 (Galeno, 2020; Wang and Lin, 2024). However, this growth was uneven across socioeconomic and geographic contexts (Zapletal et al., 2023; Haelermans et al., 2022; UN, 2020).

One of the clearest manifestations of this digital inequality is found in Latin America, where, during the COVID-19 pandemic, less than 42% of the urban population and only 14% of the rural population had internet access (LEE, 2020). This contrasts with countries in the Global North, including the United States, where internet connectivity reached 77% in urban areas and 73% in rural areas, and the European Union, where the corresponding figures were 82% and 68%. These differences reflected substantial disparities in educational response capacity during lockdown. In Latin America, the digital divide has been linked to differences in the access, coverage, and affordability of public information and communication technology (ICT) services (Becerra and Mastrini, 2017). At the same time, the health emergency accelerated digitalisation processes and the expansion of connectivity in response to the educational demands imposed by lockdown (Olson et al., 2025; Clercq et al., 2023; Busuttil and Farrugia, 2020; Morata-Sanz, 2020).

In response, Latin American governments implemented policies intended to guarantee connectivity as an essential service and sustain academic, work, and community activities remotely. Argentina, Brazil, Chile, Colombia, and Mexico, among others, adopted measures such as declaring ICT services essential, prohibiting disconnections for non-payment, freezing tariffs, and offering low-cost plans to vulnerable populations. Measures were also introduced to manage data traffic and consumption, strengthen infrastructure and radio-spectrum management, and support telecommunications operators in maintaining network availability and protecting vulnerable users. Although virtual classes, social media platforms, television, and radio became important resources for teachers, the international literature also documented inadequate or improvised infrastructure, limited teacher preparation, and restricted household access to internet services and devices, all of which affected learning quality in vulnerable settings (ENACOM, 2020; Califano and Becerra, 2024; Joshi et al., 2023).

In Colombia, limitations in broadband access have long reflected broader social, economic, and territorial inequalities (Montes, 2019). According to the Banco Mundial (2020), substantial income inequality also persisted during this period. MinTIC subsequently reported a 140% increase in 4G adoption between July 2017 and November 2019, an expansion that contributed to the technological capacity available when educational services moved online (MinTIC, 2024; Pardo-Figueroa and Obando-Fernández, 2021). Nevertheless, marked regional disparities remained: approximately half of households in the Andean and Pacific regions had fixed internet access, whereas rates in the Amazon and Orinoquía regions

remained below 20% (Kairuz, 2020). These inequalities reinforce the need to examine how connectivity gaps intersect with educational equity and how public action can strengthen technological infrastructure and ICT access.

Tunja, the capital of Colombia's Boyacá Department, provides a relevant case for examining these issues. Recognised by UNESCO as a Learning City, Tunja has a comparatively robust public education system, with approximately 18.3% of its 200,000 inhabitants enrolled in basic, middle, and secondary education institutions (SIMAT, 2020). However, it remained unclear how strongly institutional socioeconomic vulnerability was associated with connectivity across public schools during the crisis, how connectivity changed between the peak of lockdown and the following year, and whether resource provision corresponded to improvements in the most vulnerable institutions. In line with the concepts of efficiency and accountability (Reuge et al., 2021), this study treats efficiency as the alignment between technological resources allocated through public policy and observed institutional connectivity outcomes, while accountability concerns the prioritisation of institutions facing greater socioeconomic disadvantage. Accordingly, the study aims to: (i) characterise the technological and connectivity conditions of public schools in Tunja during full social isolation (2020) and one year later (2021); (ii) analyse the association between institutional socioeconomic index and internet access during the study period; and (iii) describe the distribution of equipment and connectivity measures implemented by the local administration in relation to observed changes in the digital divide among schools under its jurisdiction.

This paper is structured as follows: the next section describes the data collection and analytical methods; subsequently, the results are presented; this is followed by a discussion of the findings in dialogue with the literature; and it concludes with recommendations aimed at advancing digital inclusion in vulnerable educational contexts.

MATERIALS AND METHODS

Study Area

The study was conducted in Tunja, capital of the department of Boyacá, Colombia. Founded in 1539, Tunja is recognised as a UNESCO Learning City and as the birthplace of Colombia's public education system, established on 17 May 1822 through an initiative led by Vice President Francisco de Paula Santander and Secretary of the Interior José Manuel Restrepo (Colboy, 2020). Since then, Tunja has maintained a longstanding educational tradition and has been recognised for strong performance in national standardised assessments (Moreno-Villamil, 2023; Rivera, 2013).

The public primary and secondary education network of Tunja consists of 14 schools managed by the local administration, serving approximately 23,000 students, representing 64.0% of the city's total enrolment of 35,971 students. This study is an institutional census. All 14 public schools under the jurisdiction of the municipal education authority were included in the census in both 2020 and 2021. The results should not be generalised to private institutions or other municipalities without comparable administrative and socio-economic contexts.

Tunja was certified as an autonomous educational entity by Resolution No. 2755 of 3 December 2002, issued by the Ministry of National Education. The city has maintained nationally recognised education-quality initiatives and has performed strongly in the Saber 11 assessments among public institutions. The local administration provides broadband

internet service to 37 official school sites under its authority, located in central urban (15), peri-urban (21), and rural (1) areas (Figure 1, Table 2). Nevertheless, access to and use of digital technologies remain more limited among vulnerable populations, particularly in rural and peripheral areas in the southern part of the city.

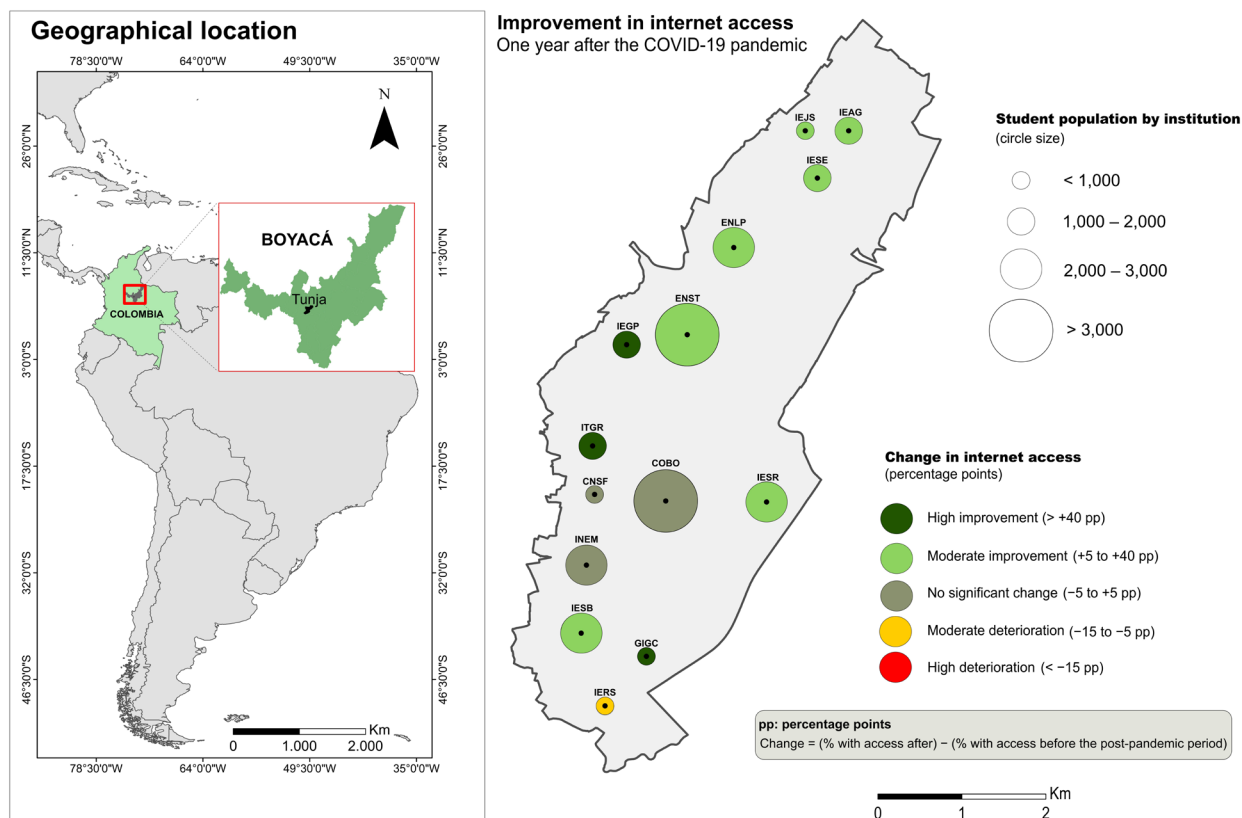


Figure 1: Study area. Left panel: location of Boyacá within Colombia and South America, with the urban boundary of Tunja shown in black. Right panel: location of schools, each represented by a circle. Circle size is proportional to the average student population over the study period (2020–2021). Circle colour indicates the change in the proportion of students with internet access (percentage points, pp), calculated as the percentage with access in 2021 minus the percentage with access in 2020. Population size categories and change ranges are detailed in the legend. Table 2 lists the reference codes for the institutions and associated complementary information. Reference system: WGS84 / UTM Zone 18N (EPSG: 32618).

Information collection

The research was conducted in accordance with Colombia's ethical protocols for information management and human participant research (Resolution 8430 of 1993, Ministry of Health). The dataset analysed in this study corresponds to administrative information collected by the Municipal Secretariat of Education of Tunja within its statutory framework to evaluate and consolidate municipal educational data (Law 115 of 1994, Article 151; Resolution No. 2755 of 2002, Ministry of National Education). This study constitutes a secondary analysis of pre-existing institutional records rather than primary research involving the active recruitment of human participants. Table S2 corresponds to a blank template of the internal classroom-level tracking instrument used by each principal to compile teachers' reports within the institution; it was not submitted to the Municipal Secretariat of Education or to the research team. Consequently,

although the template included a field for the teacher's name for internal administrative use by the principal, this identifying information never left the institution and was not accessible to, or processed by, the research team. The methods employed correspond to documentary and secondary analysis techniques, categorized as low-risk under Article 11(a) of Resolution 8430 of 1993. Consequently, given the secondary, anonymized, and aggregated nature of the data, individual informed consent and formal ethics committee review were not required. The instruments were supervised and validated through review by the professional team of the Educational Quality Division of the Municipal Secretariat of Education. Formal communication with public educational institutions was carried out under Resolution 00237 of 2020, and Circular No. 090 of 2021 enabled the reapplication of the instruments to compare data across both periods.

Data collection operated through a two-level procedure. At the classroom level, teachers completed a structured

survey covering student internet access, available devices, and pedagogical communication tools used during remote instruction (Table S2). Each teacher reported exclusively on their own assigned group of students, with mutually exclusive, non-overlapping student rosters across teachers within a school, preventing double counting at the classroom level. Because each student was enrolled in only one classroom group per year, and each teacher's roster was restricted to their own assigned group, no student could be reported by more than one teacher, even across different campuses of the same institution. Percentages of communication-tool usage reported in Figure 4 correspond to the total number of students reached through each channel, relative to total enrolment for each year (Table 1), consistent with the denominator used in Table 3. At the institutional level, school principals consolidated these non-overlapping group-level reports into the institutional-level form (Table S1), and the resulting totals were subsequently reconciled against official per-grade enrolment recorded in SIMAT (Sistema de Matriculas Estudiantil), Colombia's official student enrolment system, providing an additional safeguard against double counting. Both instruments were designed and administered via Google Forms and together comprised more than 30 response fields organised across six thematic sections. Before completion, the instruments and their objectives were shared with teachers and school administrators to ensure accurate and consistent responses across all campuses. Although a formal pilot study was not possible in the context of the pandemic emergency, expert review, institutional authorisation, and socialisation with participants served as the primary mechanisms for ensuring the validity and reliability of the collected data. The same procedure was applied identically in 2020 and 2021.

For the purposes of this study, internet connectivity was defined as any form of functional internet access available for educational activities, including broadband and mobile data connections. This definition encompasses the two modalities reported separately in the surveys and underpins the aggregated connectivity indicators used throughout the analyses. All 14 public schools participated in both study periods (2020 and 2021), achieving full institutional coverage of the target population.

Information systematization

After data collection, the information was tabulated and analysed using R version 4.4.2 and Microsoft Excel 2016. Data reported by each institution were subjected to internal consistency checks, including verification of totals and

proportions, and were cross-referenced with official enrolment figures recorded in SIMAT for each year. Minor discrepancies of less than 1% were verified directly with the corresponding institution before the database was finalised.

For historical equipment inventories from 2020 and selected administrative records of technological provision, not available (NA) values occurred for Colegio de Boyacá and Colegio Nuestra Señora de Fátima (Table 4) because consolidated reports were unavailable or administrative records were still being updated during data collection.

Missing data management

Because the study was an institutional census ($n = 14$), no missing values were recorded for the primary study variables (connectivity, number of students, and socioeconomic stratification), all of which were cross-checked against the SIMAT database. NA values occurred only in secondary variables related to technological inventories and equipment-provision records for two institutions, as described above. These cases were excluded from the relevant descriptive summaries; no statistical imputation was performed.

Information analysis

Descriptive statistics were computed for connectivity and socioeconomic status. The unit of analysis was the public school ($n = 14$). Unless otherwise indicated, the unweighted mean of the 14 school-level connectivity percentages (Table 2) was adopted as the primary estimand of this study, consistent with the institutional census design and unit of analysis, and is reported consistently across the text, tables, and figures. These values differ from the enrolment-weighted proportions derived from the raw totals in Table 1 (45.4% in 2020 and 69.7% in 2021), which arise because the weighted calculation gives proportionally greater influence to schools with larger enrolments in the resulting average; these values are reported here once, for transparency, and are not used elsewhere in the manuscript. The Shapiro–Wilk test was used to assess the distribution of within-school changes in connectivity between 2020 and 2021 ($W = 0.958$, $p = 0.695$) before applying the paired-samples t-test. Pearson correlation coefficients were used to examine the association between average school-level connectivity and the socioeconomic index. The index was calculated as the percentage of enrolled students, from pre-school to Year 11, belonging to the most vulnerable socioeconomic categories (strata 0 and 1) according to the Colombian socioeconomic classification system (Bonilla et al., 2014), using the following formula:

$$\text{Socioeconomic index} = \frac{\text{No. of students in strata 0 and 1}}{\text{Total enrolled students}} \cdot 100$$

Note: All index values were derived exclusively from SIMAT records, without additional transformations. The strata considered correspond exclusively to strata 0 (very low) and strata 1 (low). For example: the Institución Educativa Libertador Simón Bolívar reported 1,170 students in strata 0 and 1 out of a total of 1,334 enrolled students, representing a Socioeconomic Index of 87.7%.

Pearson's product-moment correlation coefficient (r) was used to quantify the association between school-level connectivity and the socioeconomic index. The coefficient of determination ($R^2 = r^2$) was reported as the proportion of variance in connectivity statistically associated with the socioeconomic index. Because the same 14 institutions were observed in 2020 and 2021, between-year comparisons were conducted

using a paired-samples *t*-test on school-level connectivity percentages, thereby accounting for the paired institutional structure. In addition, an ordinary least squares (OLS) model was fitted with year as a binary predictor (2020 = reference; 2021 = 1). Standard errors were clustered at the school level to account for repeated observations within institutions.

Statistical analysis

Analyses were aligned with the study objectives. To characterise changes in connectivity between 2020 and 2021 (Objective I), a paired-samples *t*-test was performed on school-level percentages. To examine the association between institutional socioeconomic vulnerability and connectivity (Objective II), Pearson correlation coefficients (*r*) were calculated for each year at school level; and (Objective III), concerning the distribution of equipment and connectivity measures implemented by the local administration, was addressed descriptively; no inferential analysis was performed to test whether resource allocation predicted connectivity change or was proportional to institutional vulnerability. Finally, an OLS regression model with year as a binary predictor (2020 = reference; 2021 = 1) was used as a supplementary analysis of average change over time, with school-clustered standard errors to account for repeated observations. Cluster-robust standard errors were estimated using the CR2 bias-reduced linearisation correction with Satterthwaite degrees of freedom (Pustejovsky and Tipton, 2018), which is recommended when the number of clusters is small. Because the dataset comprises the full population of public schools under municipal jurisdiction rather than

a probability sample, inferential statistics are interpreted as model-based evidence regarding the observed pattern rather than as conventional finite-population sampling inference.

RESULTS

This section presents the results of the comparative analysis of connectivity and the socioeconomic characterization of public schools in Tunja. The analysis included all 14 public schools under municipal jurisdiction in both 2020 and 2021, corresponding to a 100% institutional coverage rate in both periods. All results are based on school-level aggregated data (*n* = 14), consistent with the census design of the study.

For descriptive purposes, schools were grouped according to the proportion of students in vulnerable socioeconomic strata and changes in internet coverage across the two study years. The comparison of school-level connectivity in 2020 and 2021 provides insight into how access changed during the COVID-19 emergency. These patterns should be interpreted cautiously because location and other unmeasured institutional and territorial factors may also have influenced connectivity outcomes.

At the school level, the mean proportion of students without internet access was 56.5% in 2020, while the mean proportion with access was 43.5% (Figure 2). By 2021, mean school-level connectivity had increased to 67.5%, corresponding to an average within-school gain of 24.0 percentage points. In terms of raw student counts, the number reported as having internet access increased from 10,655 to 16,394, a difference of 5,739 students (Table 1).

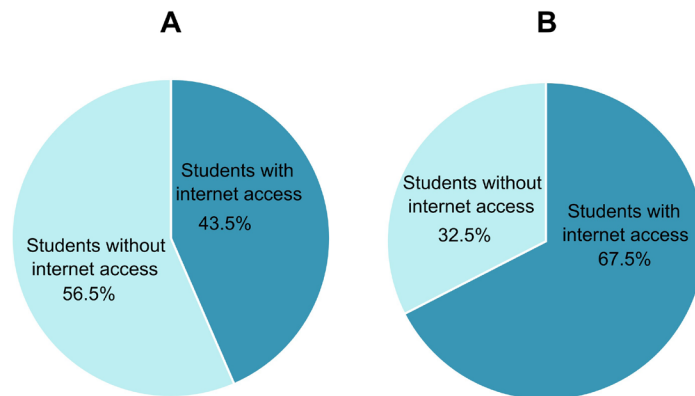


Figure 2: Student population surveyed. A. Students with/without internet access in 2020, B. Students with/without internet access in 2021. Percentages correspond to the unweighted mean of school-level connectivity percentages (see Methods).

Despite the restrictions of the pandemic, the student population recorded in the Student Enrolment System (SIMAT) remained

stable, from 23,474 students in 2020 to 23,509 in 2021, which represents a marginal variation of 0.1% (Vargas, 2021).

Variable	2020	2021
	Number of students	Number of students
Students with internet access	10,655	16,394
Students without internet access	12,819	7,115
TOTAL	23,474	23,509

Table 1: Students with broadband internet access vs. without connectivity

School Typology

The descriptive comparison identified three broad ranges of school connectivity for interpretative purposes. These ranges were defined post hoc based on the observed distribution of connectivity values and were used solely to facilitate descriptive comparison, rather than through a formal clustering or classification procedure. Schools with connectivity above 90% tended to have lower socioeconomic index values and were generally located in central urban areas. Schools with intermediate connectivity (approximately 50–80%) generally showed socioeconomic index values of roughly 25–40%, whereas schools with connectivity below 50% were more commonly located in peri-urban or rural areas and tended to serve more socioeconomically vulnerable populations (Figure 1, Table 2). The socioeconomic-index ranges were likewise used descriptively to characterise the observed patterns and do not represent statistically derived classification thresholds. In 2020, connectivity was concentrated in the north and centre of the city. CNSF, COBO, and IESE reported coverage above 80% and were located in areas with comparatively better urban infrastructure. By contrast, several schools in western and southeastern areas, including IESR, ITGR, and IERS, reported internet access below 20%, illustrating the substantial territorial variation in connectivity at the start of the remote-learning period (Figure 1, Table 2).

By 2021, connectivity had improved in many schools, although substantial differences remained. COBO and CNSF reported fewer than 3% of students without access, while several schools with intermediate baseline connectivity showed marked gains. ENLP increased from 59.6% in 2020 to 95.0% in 2021, and IEJS and ENST exceeded 70% connectivity. These changes

occurred during the same period in which devices, SIM cards, and network improvements were introduced (Table 4), although the present analyses do not establish that these interventions caused the observed changes.

Among the most vulnerable peripheral and rural schools, improvements were more limited and heterogeneous. Although ITGR increased from 6.5% to 75.0% connectivity, IESR reached 48.5%, while other highly vulnerable institutions remained at substantially lower levels. Overall, connectivity became more widespread by 2021, but low-connectivity areas persisted, particularly in the southwestern part of the municipality (Figure 1).

A strong inverse association was observed between the Socioeconomic Index and average school connectivity in both 2020 (Pearson's $r = -0.804$, $t(12) = -4.69$, $p = 0.00053$) and 2021 (Pearson's $r = -0.794$, $t(12) = -4.53$, $p = 0.00069$), corresponding to R^2 values of approximately 65% and 63%, respectively (Figure 3). The similarity of the coefficients across the two years indicates a persistent association between institutional socioeconomic vulnerability and connectivity coverage in this setting. A paired comparison showed that average school-level connectivity was higher in 2021 than in 2020 ($t(13) = 3.91$, $p = 0.0018$), with an average gain of 24.0 percentage points (95% CI [10.7, 37.2]). An OLS regression with year as a binary predictor produced the same estimated mean difference ($B = 24.0$ percentage points; cluster-robust SE = 6.12; CR2 bias-reduced linearisation with Satterthwaite degrees of freedom; $t(13) = 3.91$, $p = 0.0018$; 95% CI [10.8, 37.2]; $n = 28$ observations, 14 clusters). Given the small number of clusters, this regression is presented as supplementary evidence corroborating the paired-samples analysis rather than as an independent causal estimate.

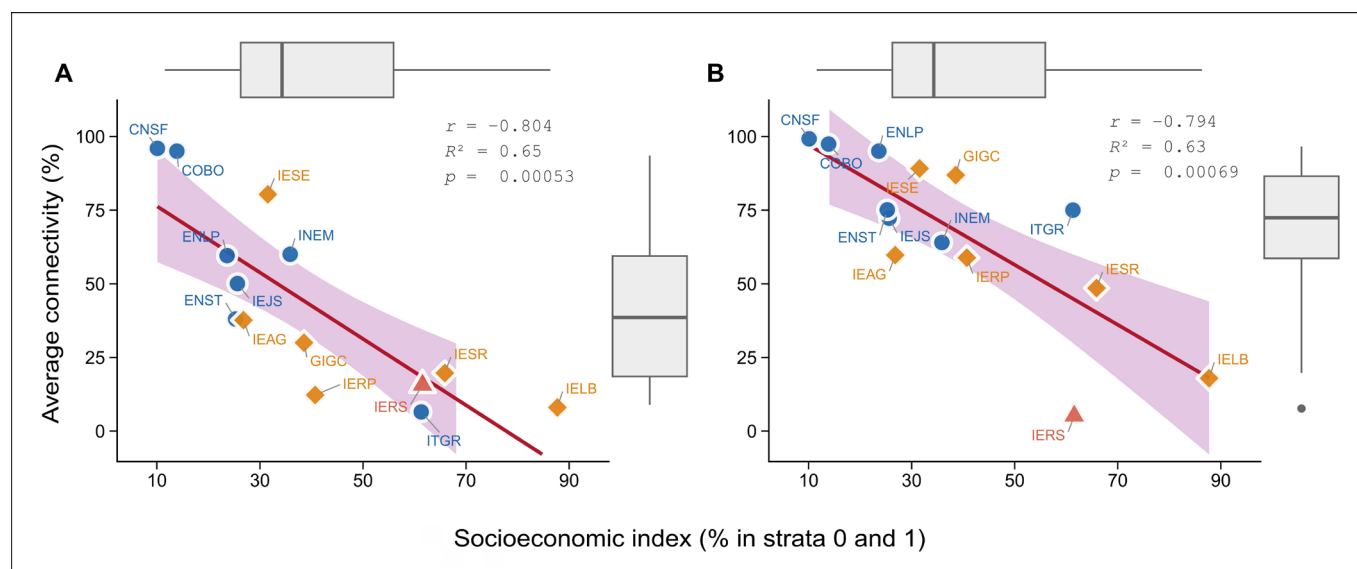


Figure 3: Pearson correlation between the Socioeconomic Index and average internet connectivity (%) across the 14 public schools of Tunja, Colombia, in (A) 2020 and (B) 2021. Each point represents one school, identified by its acronym (see Table 2) and classified by spatial location: urban (blue circles), peri-urban (amber diamonds), and rural (terracotta triangles). The red line represents the linear regression fit; the shaded band indicates the 95% confidence interval. Marginal boxplots display the univariate distribution of each variable. Statistical annotations report Pearson's correlation coefficient (r), coefficient of determination (R^2), and the associated p -value.

Public Schools	Code	Number of school sites	Spatial classification	Socioeconomic Average Percentage (Σ Stratum 0–1)	2020				2021			
					Students with internet access	Percentage %	Students without internet access	Percentage %	Students with internet access	Percentage %	Students without internet access	Percentage %
Colegio Nuestra Señora de Fátima	CNSF	1	Urban	10.1%	357	96.0%	15	4.0%	384	99.2%	3	0.8%
Colegio de Boyacá	COBO	3	Urban	13.9%	2,939	95.0%	154	5.0%	2,999	97.4%	79	2.6%
I.E. San Jerónimo Emiliani	IESE	3	Peri-urban	31.5%	1,191	80.4%	291	19.6%	1,482	89.2%	159	10.8%
INEM Carlos Arturo Torres	INEM	3	Urban	35.9%	1,432	60.0%	954	40.0%	2,386	64.0%	888	36.0%
Escuela Normal Superior Leonor Álvarez Pinzón	ENLP	1	Urban	23.6%	1,390	59.6%	943	40.4%	2,333	95.0%	117	5.0%
Institución Educativa Julius Sieber	IEJS	1	Urban	25.6%	361	50.1%	360	49.9%	721	72.3%	195	27.7%
Escuela Normal Superior Santiago de Tunja	ENST	2	Urban	25.3%	1,280	38.0%	2,085	62.0%	3,365	75.1%	856	24.9%
Institución Educativa Antonio José Sandoval Gómez	IEAG	3	Peri-urban	26.8%	400	37.7%	662	62.3%	1,062	59.7%	445	40.3%
Gimnasio Gran Colombiano	GIGC	1	Peri-urban	38.6%	266	30.0%	621	70.0%	887	86.9%	114	13.1%
Institución Educativa Silvino Rodríguez	IESR	7	Peri-urban	65.9%	540	19.7%	2,201	80.3%	2,741	48.5%	1,376	51.5%
Institución Educativa Rural del Sur	IERP	1	Rural	61.5%	147	15.6%	793	84.4%	940	5.2%	901	94.8%
Institución Educativa Rojas Pinilla	IERP	2	Peri-urban	40.7%	140	12.3%	1,003	87.7%	1,143	58.9%	441	41.1%
Institución Educativa Libertador Simón Bolívar	IELB	5	Peri-urban	87.7%	107	8.0%	1,227	92.0%	1,334	17.9%	1,157	82.1%
Instituto Técnico Gonzalo Suarez Rendón	ITGR	4	Urban	61.3%	105	6.5%	1,510	93.5%	1,615	75.0%	384	25.0%
TOTAL	--	37	--	--	10,655	43.5%	12,819	56.5%	23,474	67.5%	7,115	32.5%

Note: In the TOTAL row, the 'Students with internet access' and 'Students without internet access' columns represent the sum of raw student counts across the 14 schools, whereas the adjacent 'Percentage %' columns represent the unweighted mean of the corresponding school-level percentages. Therefore, these percentages do not correspond to the ratio of the total number of students with internet access to total enrolment.

Table 2: Socioeconomic index and connectivity of Public Schools

The device-access categories reported in Table 3 correspond directly to Section 3 of the classroom-level instrument (Table S2): laptop with/without internet, tablet, mobile phone with/without data, and ‘none of the above’, which teachers reported as percentages of their assigned student groups. These categories were mutually exclusive, with each student classified under a single predominant device-access condition. This exclusivity is supported by the fact that the six category percentages sum to approximately 100% in

both years (100.00% in 2020 and 99.99% in 2021, Table 3), with the minor deviation from 100% attributable to rounding. Access to internet-enabled devices increased between the two study years. The percentage of students reported as having laptops with internet access rose from 22.90% in 2020 to 26.86% in 2021, while the percentage with laptops without internet access increased from 9.09% to 16.34%. The proportion reported as using mobile phones with data plans increased from 24.40% to 26.59% (Table 3).

Year	Technological Means	N° students	%
2020	Laptops with internet	5,376	22.90%
	Laptops without internet	2,134	9.09%
	Tablet	444	1.89%
	Mobile phones with data	5,728	24.40%
	Mobile phones without data	6,398	27.26%
	None of the above	3,394	14.46%
2021	Laptops with internet	6,315	26.86%
	Laptops without internet	3,842	16.34%
	Tablet	673	2.86%
	Mobile phones with data	6,250	26.59%
	Mobile phones without data	4,082	17.36%
	None of the above	2,347	9.98%

Note: Each variable is measured over the total number of students for each year, equivalent to 23,474 students in 2020 and 23,509 students in 2021 according to SIMAT, with data provided by the Public Schools through the survey responses.

Table 3: Digital and audiovisual devices.

The proportion of students reported as having mobile phones without data plans decreased by 9.9 percentage points, while the proportion without any listed device decreased by approximately 4.5 percentage points. The SIM-card distribution programme reached 27.9% of enrolled students (Table 4). Nevertheless, rural areas continued to face substantial connectivity constraints related to infrastructure, device availability, and socioeconomic disadvantage.

Dynamics of pedagogical interaction in virtual environments

Among the communication channels used for remote teaching and learning, email reached 92.9% of enrolled students in 2021 compared with 62.0% in 2020. Videoconferencing showed the largest absolute increase, rising from 26.2% to 85.7%. Use of institutional virtual platforms increased by 26.5 percentage points, and social media by 23.1 percentage points (Figure 4), indicating broader use of digital communication channels during the second study year.

Frequently reported tools included WhatsApp, Google Meet, Google Classroom, Skype, and Zoom, which supported synchronous and asynchronous interaction. By contrast, platforms such as Facebook, Twitter, and Instagram were reported less frequently for structured educational communication.

Institutional strategies and provision of resources

Local and national authorities expanded technological provision during the study period. In total, 2,838 laptops were reported as delivered to the institutions, of which 1,073 were financed with local government funds and 1,765 were procured through the national programme ‘Computadores para Educar’

(Table 4). Reported laptop provision was distributed across schools with differing levels of socioeconomic vulnerability, including several rural and peri-urban institutions. However, this distribution is descriptive, and the present analysis does not test whether allocation was statistically proportional to institutional vulnerability.

Additionally, 6,567 SIM cards with mobile data were distributed as a measure to mitigate connectivity gaps, complemented by the installation of Wi-Fi zones and broadband expansion. These actions sought to ensure internet access in classrooms. Nevertheless, persistent limitations were identified in implementation, due to logistical delays, technical infrastructure constraints, and irregular coverage in certain areas. Such factors require priority attention to achieve continuous improvement in the provision of educational connectivity.

Finally, platforms promoted by the Ministry of Education of the national government, such as Colombia Aprende, offered more than 80,000 open-access digital resources for students, teachers, and families. The use of platforms such as Edmodo was also recorded, which facilitated the management of assignments, assessments, and content in a private and secure manner, promoting more structured and functional virtual learning environments (MEN, 2020).

DISCUSSION

The findings of this study suggest that the inequalities observed during the pandemic may have reflected pre-existing territorial and socioeconomic asymmetries in Tunja, rather than being entirely caused by the pandemic itself. However, as this study lacks a pre-pandemic baseline, it is not possible to empirically determine whether these inequalities predated

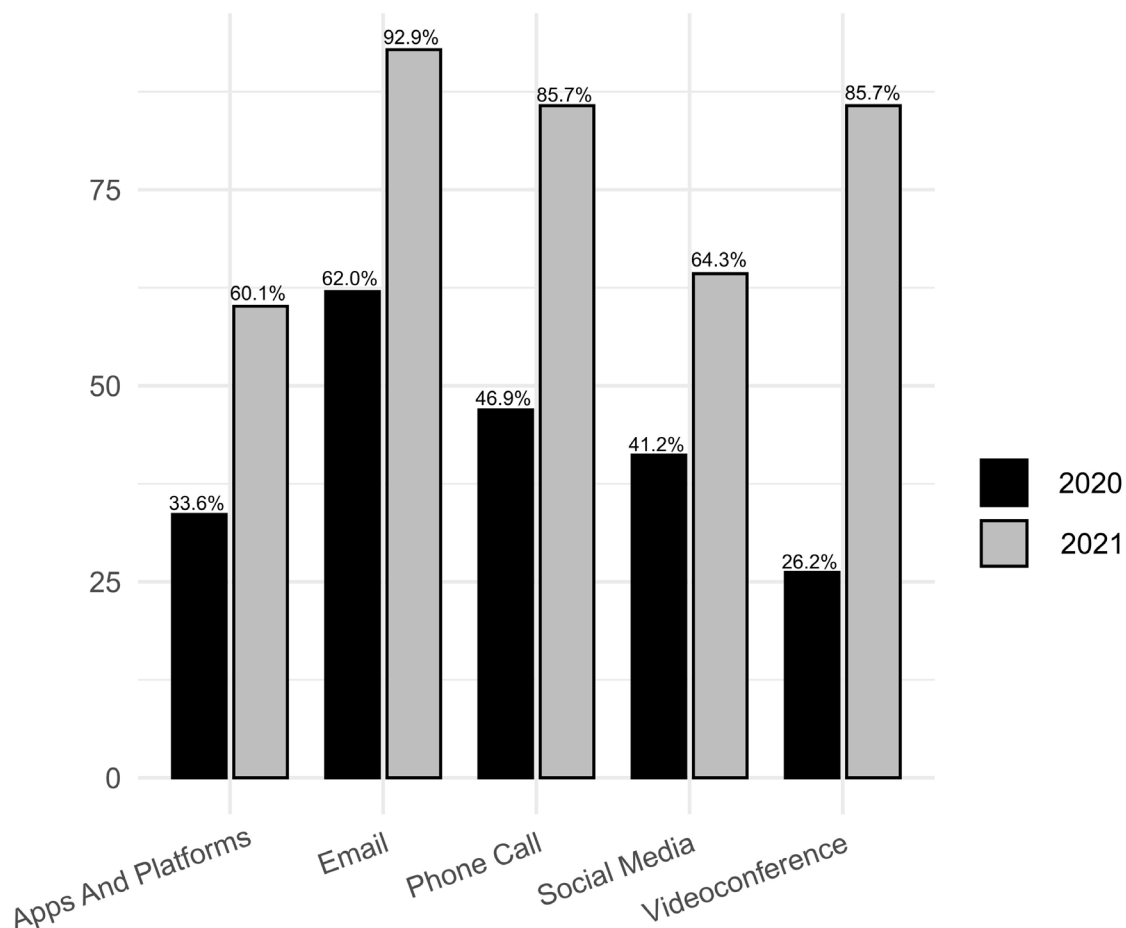


Figure 4: Percentage of virtual interaction media used by teachers in public schools. Note: Percentages represent the proportion of students reached through each communication channel relative to total enrolment for each year (23,474 in 2020; 23,509 in 2021).

Public Schools of Tunja	Number of laptops		Local government support		
	Inventory 2020	Inventory 2021	SIM Card Delivery	Laptops Delivery	TOTAL
Institución Educativa San Jerónimo Emiliani	NA	90	400	90	490
Instituto Técnico Gonzalo Suarez Rendón	120	160	700	75	775
Institución Educativa INEM Carlos Arturo Torres	57	406	500	349	849
Institución Educativa Julius Sieber	15	35	400	20	420
Institución Educativa Libertador Simón Bolívar	44	179	700	150	850
I.E. Rural del Sur	25	745	800	720	1,520
Normal Superior Leonor Álvarez Pinzón	65	309	500	244	744
Institución Educativa Silvino Rodríguez	30	55	767	75	842
Institución Educativa Rojas Pinilla	40	170	400	130	530
Colegio Gran Colombiano	21	186	500	165	665
Escuela Normal S. Santiago de Tunja	28	338	500	310	810
Institución Educativa Antonio José Sandoval Gómez	127	277	400	150	550
Colegio de Boyacá	NA	360	NA	360	360
Colegio Nuestra Señora de Fátima	NA	NA	NA	NA	NA
TOTAL	572	3,310	6,567	2,838	9,405

Table 4: Supply of laptops and delivery of SIM cards to Public Schools in 2020 and 2021.

the pandemic or were created or exacerbated by it. This interpretation is consistent with the growing international literature on the educational impacts of the pandemic, which documents how pre-existing socioeconomic and territorial

disparities shape unequal access to educational opportunities during periods of school disruption (Alejo, 2024; Wöbbekind et al., 2025). Although overall connectivity improved by 24.0 percentage points, this improvement was not proportional to

the magnitude of need in the most vulnerable sectors. This pattern is consistent with the inverse correlation observed between the socioeconomic index and average connectivity. While urban schools such as COBO and CNSF achieved over 97% connectivity in 2021, peripheral schools with low socioeconomic profiles, such as IELB and IERS, remained below 20%. According to Bracco et al. (2025), such disparities are not an isolated concern: accumulated learning losses in Latin America during the pandemic may have intergenerational implications for the formation of human capital among the most vulnerable populations.

For descriptive interpretation, schools were grouped into the three post hoc connectivity ranges described above, based on observed connectivity, socioeconomic index, and location. Two cases were particularly notable. IERS, the only rural school in the census, received the largest combined package of laptops and SIM cards reported in Table 4 (1,520 resources), yet its connectivity declined from 15.6% to 5.2%. IELB, which served the most socioeconomically vulnerable student population in the census (87.7% in strata 0 and 1), received 850 combined resources while connectivity increased from 8.0% to 17.9%. These contrasting patterns illustrate that greater resource provision did not invariably coincide with larger connectivity gains; however, the descriptive design does not establish the causal effect of resource allocation.

According to van Dijk (2005), the digital divide extends beyond the provision of devices and connectivity and also encompasses differences in the skills, conditions, and opportunities required to use digital resources effectively. The Tunja data are consistent with this broader perspective because technological provision did not uniformly coincide with improvements in connectivity. For example, IERS, the rural school with high socioeconomic vulnerability, declined from 15.6% to 5.2% connectivity despite receiving substantial technological resources. This pattern suggests that resource provision alone may not overcome structural territorial disadvantages. In settings characterised by unstable infrastructure, poor signal coverage, limited technical support, or constrained household capacity, devices may not translate directly into sustained educational access (Kennedy et al., 2022; Katz et al., 2025).

Mobile telephony played an important role in maintaining communication between schools and students. The SIM-card programme reached 27.9% of enrolled students. However, connectivity gains remained limited in some peri-urban and rural institutions, where intermittent signal coverage, limited access to suitable smartphones, and socioeconomic disadvantage may have constrained the usefulness of mobile-data provision. Across Latin America, 87% of the population lives within 4G coverage, yet mobile-internet penetration is substantially lower and fewer than half of households have fixed broadband access (WEF, 2021; World Bank, 2024). This distinction between nominal coverage and functional access is relevant to the persistent gaps observed in vulnerable educational settings in Tunja.

The marked expansion of digital communication channels between 2020 and 2021 is consistent with a substantial reconfiguration of teacher-student interaction during the pandemic. Videoconferencing showed the greatest

relative growth, suggesting an effort to reproduce elements of synchronous, real-time classroom interaction in remote settings. This is understandable given the limited availability of consolidated alternative models in basic education during the emergency period (Hodges et al., 2020; Bozkurt and Sharma, 2020). The simultaneous increase in email, telephone calls, and social media may also have functioned as a compensatory response for students unable to participate consistently in synchronous sessions. Muñoz-Najar et al. (2021) describe a comparable ‘staggered channel portfolio’, in which the choice of communication medium is constrained by the infrastructure available in students’ homes. These interpretations are consistent with the observed communication patterns but were not tested directly in the present dataset.

One notable development coinciding with the pandemic in public institutions in Tunja was the expansion of the digital educational ecosystem. Virtual platforms such as Colombia Aprende, Edmodo, Google Classroom and Google Meet, which had previously been underutilised, were widely adopted, ensuring the continuity of educational services. This coincides with a global trend of sustained growth in the interest of students, teachers and families in ICT-mediated learning resources (Radha et al., 2020; Arnett, 2021). Tunja is a UNESCO Learning City and, according to the Competitive Cities Index 2021 (CCI, 2021), the third Colombian city in terms of fixed broadband penetration and digital coverage. It has an institutional foundation upon which to consolidate this transformation, provided that efforts in vulnerable settings are strengthened in line with the objectives of Colombia’s National Digital Strategy 2023–2026. This strategy identifies reducing regional disparities and strengthening digital competencies in the education sector as national priorities (MinTIC, 2023).

From a normative perspective, the findings of this research make a valuable contribution to contemporary debates on the right to education in societies where there is a digital divide. The case study of Tunja showed that ensuring educational access in the digital era requires more than just the formal availability of technology. The convergence of pandemics, climate crises and geopolitical instability poses a constant and escalating threat to the educational continuity of the most vulnerable populations. The World Economic Forum’s 2024 Global Risks Report warns that, if commercial and geopolitical interests prevail over the public interest, the digital divide between high- and low-income countries will deepen. This will leave the most vulnerable communities isolated from digital advances impacting education, the economy, and health (WEF, 2024). Furthermore, the 2024 Report on the Sustainable Development Goals identifies the ongoing impact of the pandemic, escalating conflicts, geopolitical tensions and climate chaos as the main obstacles to educational progress worldwide (UN DESA, 2024). Thus, efficient educational inclusion hinges on the interplay of material infrastructure, institutional capacity, pedagogical mediation, and social conditions that facilitate meaningful participation in digital learning environments.

Recent research in Latin America argues that educational digital-inclusion policies should combine affordable infrastructure with contextualised services and mechanisms that support informed community participation, particularly among vulnerable groups

(Plaza de la Hoz, Espinosa Zárate and Camilli Trujillo, 2024). From this perspective, efficiency in resource allocation and accountability toward institutions facing greater structural disadvantage are complementary dimensions of educational governance (Reuge et al., 2021; Zapletal et al., 2023; Gottschalk and Weise, 2023). The present findings show that higher connectivity alone did not eliminate the socioeconomic gradient in access across schools. Reducing digital inequality therefore requires territorially sensitive and pedagogically grounded policies that can translate technological access into meaningful educational opportunities (Ramírez-Correa et al., 2025; Reuge et al., 2021; Mirazchiyski, 2025).

The findings also raise questions about Tunja's preparedness for future disruptions. In 2024, climate-related crises disrupted the education of 242 million children across 85 countries and territories, with low- and middle-income countries particularly affected (UNICEF, 2021; World Bank, 2024). Climate disasters, health emergencies, and conflicts can occur simultaneously, generating prolonged and compound crises that require educational systems to plan proactively (UNESCO, 2024; INEE, 2024). In this context, six areas warrant attention in Tunja: (i) universal, high-quality connectivity; (ii) sustained technological maintenance and territorial technical support; (iii) continuous digital-literacy programmes for teachers, students, and families; (iv) hybrid curricula designed in advance; (v) institutional monitoring capable of identifying inequalities at disaggregated territorial scales; and (vi) emerging inequalities in access to artificial-intelligence tools and capabilities. These priorities should be considered as policy implications rather than outcomes directly tested in the present study.

Several limitations should be considered. Although the census design achieved 100% institutional coverage, the analysis included only 14 school-level units, limiting precision and the stability of inferential estimates. The use of paired analyses and CR2-adjusted cluster-robust standard errors addresses the repeated-measures structure but does not eliminate the limitations associated with a small number of institutions. Connectivity was used as a proxy for educational access; however, it does not capture effective participation, quality of engagement, or academic achievement. The analysis also did not disaggregate outcomes by gender, despite the relevance of gender to digital vulnerability in Latin America (Ancheta-Arrabal et al., 2021). Finally, the two-year observation window captures change during a specific emergency period but cannot establish the sustainability of the observed gains. Longer

follow-up and replication in municipalities with different levels of institutional capacity are therefore warranted.

CONCLUSIONS

Against the backdrop of the abrupt transition to remote education during the COVID-19 pandemic, this study examined the inverse association between socioeconomic vulnerability and internet access across 14 public schools in Tunja in 2020 and 2021. The findings indicate that institutions serving more socioeconomically vulnerable student populations consistently had lower connectivity levels. Although connectivity improved substantially on average between the two years, marked differences persisted across schools, and greater reported technological provision did not invariably coincide with greater connectivity gains. These findings are consistent with regional evidence that structural interventions must extend beyond device provision if digital inequalities are to be reduced sustainably (Bracco et al., 2025).

Future research should combine connectivity data and local socioeconomic characteristics with standardised learning outcomes produced annually by the Colombian Institute for the Evaluation of Education (ICFES) to determine whether gains in digital access correspond to reductions in inequalities in academic achievement. Extending the observation period beyond the pandemic, incorporating gender-disaggregated analyses, and replicating the methodology in municipalities with lower institutional capacity would strengthen understanding of these patterns across contexts of greater structural disadvantage. Qualitative research capturing the experiences of teachers, students, and families would also provide the contextual depth needed to determine how improvements in connectivity translate into meaningful educational opportunities.

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APPENDIX

MAYOR'S OFFICE OF TUNJA – MUNICIPAL EDUCATION OFFICE

Institutional Survey on ICT Capacity, Student Connectivity, and Educational Strategies During the COVID-19 Pandemic

SECTION 1 – GENERAL INFORMATION

Name of Educational Institution:

Municipal jurisdiction? ☐ Yes ☐ No

Number of campuses:

Number of students:

Address and neighbourhood of the institution and campuses:

SECTION 2 – TEACHER ICT SKILLS

Percentage of teachers with management of ICT skills:

ICT tools used by teachers (mark all that apply):

☐ Facebook

☐ Email

☐ Storage on cloud

☐ Virtual platforms

☐ Phone calls

☐ Physical guides

☐ None

SECTION 3 – STUDENT INTERNET CONNECTIVITY

Percentage of students with internet coverage — Broadband:

Cell phone with internet — Data
mobiles %

Percentage of students without internet access:

SECTION 4 – TECHNOLOGICAL TOOLS AVAILABLE TO STUDENTS

Percentage of technological tools available to students (mark and indicate %):

☐ Storage on cloud _____ %

☐ Virtual platforms _____ %

☐ WhatsApp _____ %

☐ Phone calls _____ %

☐ Email _____ %

☐ Physical guides _____ %

☐ None _____ %

SECTION 5 – INSTITUTIONAL COMMUNICATION

Communication channel:

Circular:

SECTION 6 – CONNECTIVITY PROBLEMS AND STRATEGIES

Identify the main problems of student internet access:

Initiatives proposed to solve these problems:

Strategies that can be used to assess and monitor connectivity improvements:

Note: This form was used to collect information on connectivity, access to ICT tools, and institutional strategies during the COVID-19 pandemic in public schools of the municipality of Tunja.

Table S1: Blank template of the institutional data collection instrument administered to public school principals in the municipality of Tunja regarding connectivity, ICT tools, and institutional strategies during the COVID-19 pandemic.

MAYOR'S OFFICE OF TUNJA – MUNICIPAL EDUCATION OFFICE
Teacher Survey on Student Connectivity, Digital Device Availability, and Pedagogical Communication Strategies During the COVID-19 Pandemic

SECTION 1 – GENERAL INFORMATION

Teacher's Name: _____

Educational Institution: _____

Does the school have internet access? ☐ Yes ☐ No

Location: ☐ Urban ☐ Peri-urban
☐ Rural

SECTION 2 – STUDENT INTERNET CONNECTIVITY

Number of students WITH internet access: _____ students

Number of students WITHOUT internet access: _____ students

with internet: _____ % Mobile data _____ %

without internet: _____ % None of the above _____ %

SECTION 3 – DIGITAL DEVICES AVAILABLE TO STUDENTS

Laptop with internet _____ % Mobile phone with data _____ %

Laptop without internet _____ % Mobile phone without data _____ %

Tablet _____ % None of the above _____ %

SECTION 4 – PEDAGOGICAL COMMUNICATION TOOLS USED
(Mark and indicate % of students reached)

☐ Email _____ %

☐ Virtual learning platforms (e.g., Google Classroom, Moodle) _____ %

☐ Videoconferencing (e.g., Zoom, Google Meet) _____ %

☐ Social media (e.g., WhatsApp, Facebook) _____ %

☐ Telephone calls _____ %

SECTION 5 – MAIN PROBLEMS RELATED TO CONNECTIVITY
(Briefly describe)

SECTION 6 – RESOURCE PROVISION

Number of laptops delivered: _____ units

Number of SIM cards with data provided: _____ units

Additional connectivity actions: _____

Note: This form was used to assess students' connectivity, availability of digital devices, and use of pedagogical communication tools in public schools of the municipality of Tunja during the COVID-19 pandemic.

Table S2: Blank template of the classroom-level administrative tracking instrument internally managed by school principals to evaluate classroom teachers' student connectivity metrics, digital device availability, and pedagogical communication tools.