Where Virtual Laboratories Cannot Reach

At least 537,486 Indian schools cannot run a cloud-connected virtual science laboratory — and the schools that lack physical laboratories are disproportionately among them.

63.5%
of schools can run a cloud-connected virtual laboratory — at most

537,486
schools cannot, under any reading of the government data

124,741
secondary schools have no functional science laboratory

59.2%
of all schools are in states short of both

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Analysis of UDISE+ 2024–25, covering all 1,471,473 recognised schools.
Full data, code and the underlying research article are openly available.

EXECUTIVE SUMMARY

The remedy is least available where the problem is worst

India has a science laboratory shortage: **124,741 of 290,950 schools with secondary sections — 42.9% — have no functional integrated science laboratory.** A student in one of them can complete secondary science without ever performing a measurement.

The standard response is digital. If a school cannot build a laboratory, stream one. This argument appears throughout education-technology policy and industry, and it rests on a premise that is almost never stated: that schools without laboratories have the electricity, devices and connectivity to run the digital replacement.

This brief tests that premise against the complete 2024–25 government census of Indian school education. Three findings follow.

> **1. There is a hard ceiling.** A cloud-connected virtual laboratory needs electricity *and* a computing device *and* internet at the same time. At most **63.5%** of Indian schools have all three. At least **537,486 schools cannot run one** under any configuration consistent with the reported data. This is not a forecast — it is arithmetic on published counts.

> **2. Capacity and need point in opposite directions.** Across all 36 states and union territories, digital capacity is *lowest* where physical laboratories are scarcest ($r = -0.55$). Thirteen states containing **871,398 schools — 59.2% of every school in India** — fall below the national median on both.

> **3. Devices, not only connectivity, are the binding constraint.** Connectivity is the scarcest facility in 22 states. But in 13 states covering 482,825 schools, **devices bind first** — so offline-capable software raises reach by exactly nothing there. Bihar has internet in 84.8% of schools and a computing device in 25.2%.

What this means for policy

Virtual laboratories work. The evidence that simulation-based laboratories support conceptual learning is substantial, and this brief does not dispute it. What the data show is that their *reach* is bounded, and bounded in a way that follows the same economic gradient that created the laboratory shortage. A technology allocated by that gradient cannot flatten it.

The practical consequence is that virtual laboratories should be funded as a **complement in schools that can run them**, not as a substitution strategy for schools that cannot — because in aggregate those are not the same schools. Reaching the rest requires physical investment: laboratories, devices, or both, targeted by which constraint actually binds in each state.

What this brief does not show. It does not measure learning, and it makes no causal claim. It is an analysis of infrastructure at state level, so it cannot say that any *particular* school lacking a laboratory also lacks connectivity. And because "functional" is self-reported by schools, the figures here are an upper bound on real access — the true position is likely worse, not better.

FINDING ONE

The ceiling, and how it arises

Government statistics report how many schools have electricity, how many have a computer, and how many have internet. They do not report how many have all three — and that is the number that determines whether a cloud-delivered laboratory can run.

Because the requirements are simultaneous, the scarcest one sets the limit. Nationally that is internet, at 63.47%. No deployment can exceed it.

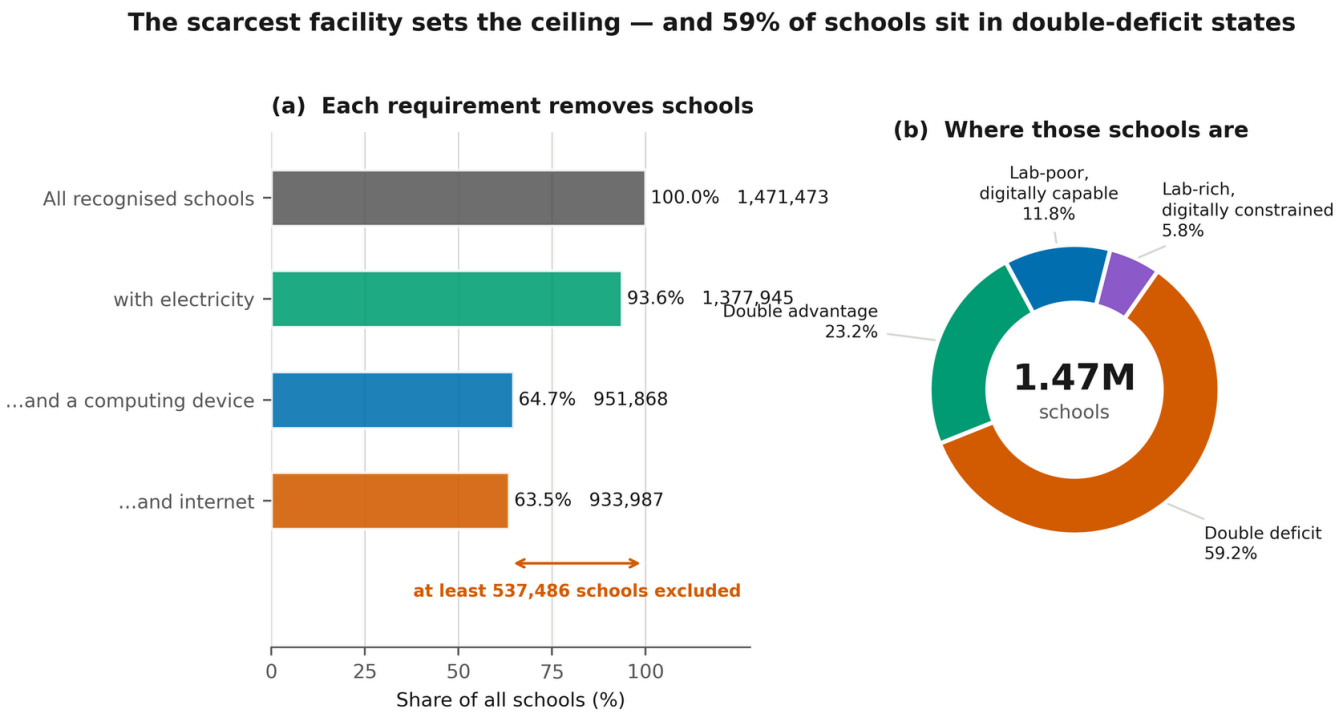

Figure 1. Left: each requirement removes schools; the smallest share sets the ceiling. Right: where the 1.47 million schools sit once states are classified by laboratory coverage and digital capacity. Areas represent schools, not states.

The published data cannot pin the figure down exactly. If the three facilities were statistically independent, 38.5% of schools would have all three; if they were perfectly nested, 63.5% would. The truth lies between, and nothing published determines where. Rather than pick a convenient assumption, this analysis reports the bounds and states conclusions that hold across the whole range.

The floor is what matters for policy, and it is assumption-free: **at least 537,486 schools — 36.5% of the system — cannot run a cloud-connected virtual laboratory.**

FINDING TWO

Capacity is lowest where laboratories are scarcest

If digital capacity were distributed independently of physical provision, substitution would at least be possible where it is needed. It is not. Across the 36 states and union territories, the two move together — so laboratory *deficit* and digital capacity move apart.

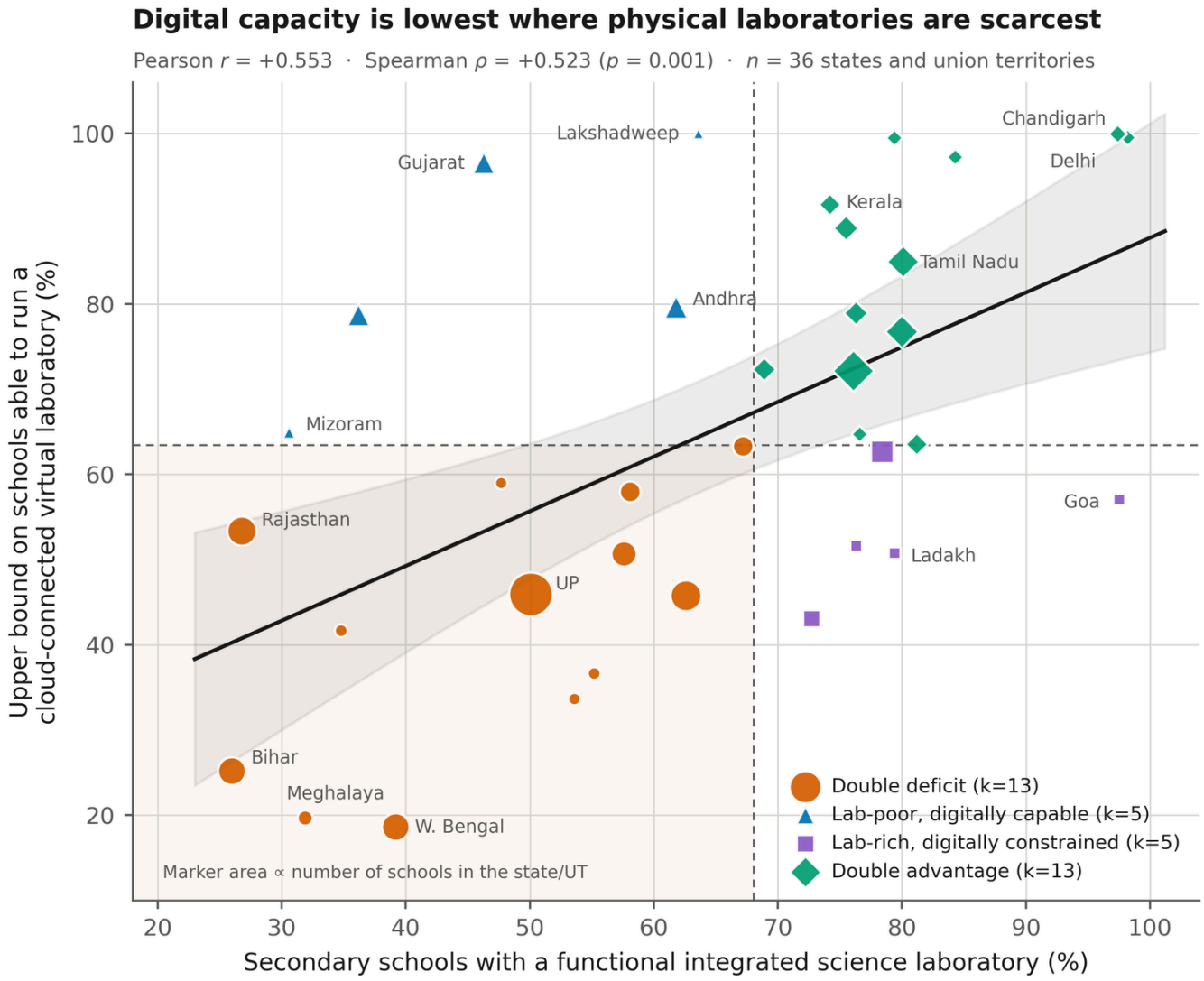

Figure 2. Each point is a state or union territory; marker area is the number of schools. States in the shaded lower-left are below the national median on both measures. The relationship is moderate, not deterministic — Gujarat, Andhra Pradesh, Assam and Mizoram combine weak laboratory provision with strong digital capacity, which shows the two *can* be decoupled by policy.

The association survives every check applied to it: removing any single state, excluding small union territories, restricting to large states, outlier-resistant estimation, comparing states only within their own region, and adjusting for per-capita state income. Adjustment for income weakens it by about a third but does not remove it.

> **The income result is the mechanism, not a nuisance.** Both laboratories and digital infrastructure track state wealth. That is precisely why a technology whose deployability depends on wealth cannot correct a shortage that wealth produced.

FINDING THREE

Which constraint binds, and where

Because the ceiling is a minimum, one facility always sets it — and which one varies by state. This determines what any given intervention can buy.

Connectivity-bound — 22 states

988,612 schools (67.2%). Internet is the scarcest facility. Offline-capable software raises the ceiling here, by up to 42 points in Sikkim, 26 in Nagaland, 25 in Tripura, 23 in Telangana, 18 in Haryana and Jharkhand.

Device-bound — 13 states

482,825 schools (32.8%). Devices are scarcer than connectivity. Offline capability raises the ceiling by **exactly zero**. The group includes Rajasthan, Bihar, Odisha, Andhra Pradesh, Chhattisgarh, Assam and Meghalaya.

Bihar is the sharpest illustration: **84.8% of its schools have internet and 25.2% have a computing device.** No software decision changes reach there. Nationally, removing the connectivity requirement lifts the ceiling only from 63.5% to 64.7%, because devices bind the moment connectivity stops binding.

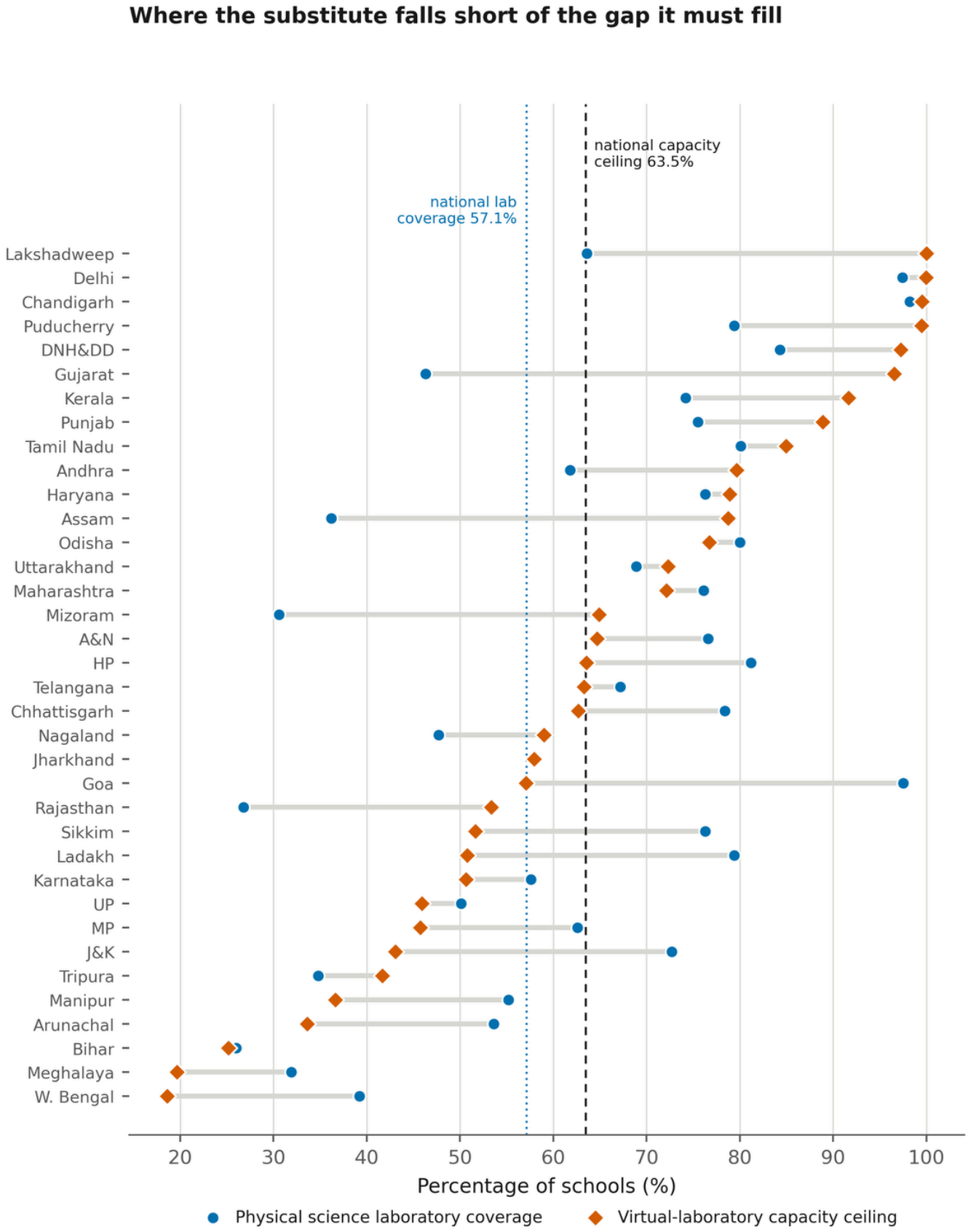

Figure 3. Laboratory coverage and digital capacity ceiling for every state and union territory, ordered by ceiling. The bar shows the distance between what a state has physically and what it could deliver digitally.

RECOMMENDATIONS

Six things that follow from the evidence

Each is addressed to whoever can act on it, and each follows directly from a finding above rather than from a general view about technology.

1 STATE EDUCATION DEPARTMENTS · MINISTRY OF EDUCATION

Stop funding virtual laboratories as a substitute strategy for laboratory-deficient schools

In aggregate, the schools that lack laboratories and the schools that can run digital replacements are not the same schools. Fund virtual laboratories as an enrichment where they can run, and fund physical provision where they cannot.

2 PROCUREMENT · PROGRAMME DESIGN

Target investment by the constraint that actually binds in each state

Connectivity programmes raise reach in 22 states and do nothing for the 482,825 schools where devices bind first. The state-by-state classification on the next page is directly usable for this.

3 PROCUREMENT · EDTECH SUPPLIERS

Require offline-first capability — and be precise about what it buys

It should be a procurement condition, because it raises reach substantially in two-thirds of schools. It should not be described as solving access, because in a third of schools it changes nothing.

4 EDTECH SUPPLIERS · PROGRAMME DESIGN

Design for shared devices and projected display, not one device per student

A large randomised evaluation across 1,823 rural government schools found learning gains at high student-to-computer ratios with minimal teacher training. Designing for 1:1 optimises for schools that are already served.

5 MINISTRY OF EDUCATION · UDISE+

Publish the cross-tabulation of electricity × device × internet

This is the single highest-value change available, and it costs almost nothing: the joint data already sit in the school-level returns. Publishing only the three separate totals leaves a 25-point uncertainty — 38.5% to 63.5% — in the number every technology decision depends on.

6 MINISTRY OF EDUCATION · RESEARCHERS

Measure functional access, not presence

"Functional laboratory" is a yes/no self-report. Earlier fieldwork with NCERT found practical work frequently obstructed even where laboratories existed. A measure that records whether students actually handled equipment would change what these statistics can support.

APPENDIX A

Every state and union territory

Ordered by number of schools. ▪ marks the thirteen double-deficit states — below the national median on both laboratory coverage and digital capacity. "Offline gain" is the percentage points the capacity ceiling would rise if the connectivity requirement were removed; a dash means offline capability changes nothing because devices already bind.

STATE / UNION TERRITORY	SCHOOLS	LAB %	CEILING %	BINDS ON	OFFLINE GAIN
▪ Uttar Pradesh	262,358	50.1	45.9	Connectivity	+14.2
▪ Madhya Pradesh	122,120	62.6	45.7	Connectivity	+13.5
Maharashtra	108,250	76.1	72.1	Connectivity	+10.4
▪ Rajasthan	106,302	26.8	53.3	Devices	—
▪ Bihar	94,339	26.0	25.2	Devices	—
▪ West Bengal	93,715	39.2	18.6	Connectivity	+6.5
▪ Karnataka	74,859	57.6	50.7	Connectivity	+5.0
Odisha	61,565	80.0	76.7	Devices	—
Andhra Pradesh	61,317	61.8	79.6	Devices	—
Tamil Nadu	57,935	80.1	84.9	Connectivity	+7.7
Chhattisgarh	56,802	78.4	62.7	Devices	—
Assam	55,283	36.2	78.7	Devices	—
Gujarat	53,355	46.3	96.5	Connectivity	+1.3
▪ Jharkhand	44,376	58.1	57.9	Connectivity	+18.0
▪ Telangana	43,154	67.2	63.3	Connectivity	+22.7
Punjab	27,281	75.5	88.9	Connectivity	+10.1
Jammu and Kashmir	24,192	72.7	43.1	Devices	—
Haryana	23,494	76.3	78.9	Connectivity	+18.4
Uttarakhand	22,452	68.9	72.3	Connectivity	+19.0
Himachal Pradesh	17,330	81.2	63.5	Connectivity	+14.3
Kerala	15,757	74.2	91.7	Connectivity	+7.9
▪ Meghalaya	14,587	31.9	19.7	Devices	—
Delhi	5,556	97.4	99.9	Devices	—
▪ Tripura	4,943	34.8	41.7	Connectivity	+24.9
▪ Manipur	4,666	55.2	36.6	Connectivity	+1.4
Mizoram	3,974	30.6	64.9	Connectivity	+11.8
▪ Arunachal Pradesh	3,229	53.6	33.6	Connectivity	+14.0
▪ Nagaland	2,750	47.7	59.0	Connectivity	+26.4
Goa	1,479	97.5	57.1	Devices	—
Sikkim	1,245	76.3	51.6	Connectivity	+42.0
Ladakh	961	79.4	50.8	Connectivity	+9.5
Puducherry	763	79.4	99.5	Devices	—
Dadra and Nagar Haveli and Daman and Diu	433	84.3	97.2	Devices	—
Andaman and Nicobar Islands	408	76.6	64.7	Connectivity	+20.1
Chandigarh	207	98.2	99.5	Devices	—
Lakshadweep	36	63.6	100.0	Electricity	—

Lab % is the share of schools with secondary sections having a functional integrated science laboratory. Ceiling % is the maximum share of all schools able to run a cloud-connected virtual laboratory. The two use different denominators; see the research article for treatment.

APPENDIX B

How to check this yourself

Every figure in this brief comes from published Government of India statistics and can be reproduced from the open repository in under a minute.

Source. Unified District Information System for Education Plus (UDISE+) 2024–25, Ministry of Education, reference date 31 March 2025. All 1,471,473 recognised schools — a census, not a sample. Per-capita state income from the Ministry of Statistics and Programme Implementation.

Validation. The transcribed state rows sum exactly to the published national totals on all seven count columns, with zero discrepancy. National rates recomputed from state counts reproduce the officially released percentages. Four independently published statements — including Uttar Pradesh's 32,599 schools without electricity and Bihar's 2,383 — reproduce exactly.

Method. Because the published data give three separate totals and not the combination, the share of schools with all three facilities is not determined. Sharp mathematical bounds are computed instead, and every conclusion is stated so that it holds at both ends of the range.

Open materials. The dataset is released as ISSIC 2024–25, a documented census with a full data dictionary, provenance for every column, six automated integrity checks and a published checksum. The analysis code regenerates every number, and an automated verifier confirms the text matches the computed values.

Status and disclosure

The underlying research article is a preprint and has not been peer reviewed. Its findings may change in review. This brief summarises the completed infrastructure analysis only; a separate study of learning outcomes is designed but has not been conducted — no participant has been recruited and no ethics approval obtained.

Competing interests. The author is associated with SciPhyLabs, an interactive physics-learning platform. This analysis uses only government administrative data and does not involve that platform. Nothing here is offered as evidence for any product's effectiveness — the analysis in fact bounds the reach of the category the author works in.

Citation

Venugopal, S. (2026). *Where virtual laboratories cannot reach: digital capacity for virtual science laboratories in Indian schools* [Research brief]. Accompanies the preprint “The Substitution Paradox: Virtual Laboratories Reach Indian Schools Least Where Needed Most.”

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