Computational Literacy and Territorial Inequality in Mexico's Digital Transition: A Spatiotemporal Analysis, 2018–2024

Alejandro Sánchez-Zárate

Salomón González Arellano

In the context of the current digital transition, individuals' computational skills have become a new dimension of social capital for improving quality of life and for envisioning better futures for the population as a whole. In this regard, efforts to measure computational skills at national and subnational scales remain limited. Thus, the objective of this study is to analyze the evolution of the level of computational literacy among the population in Mexico over the period 2018–2024. To this end, a synthetic index of computational skills is constructed, and its spatiotemporal evolution is examined across urban and rural contexts and at the state level.

Digital transition refers to the structural transformation of economies, institutions, and societies driven by the accelerated development of digital technologies such as artificial intelligence, big data, the Internet of Things, and cloud computing (Rosário and Dias, 2022). This transformation involves not only the automation of processes and the integration of digital infrastructures, but also the reconfiguration of production systems, labor markets, public services, and governance structures. At the macro level, the digital transition underpins the consolidation of the digital economy, reshaping value creation and territorial competitiveness while fostering innovation in areas such as smart cities, circular economy strategies, and digitally mediated platforms (Rosário and Dias, 2022; Oloyede *et al.*, 2023; Xia, Baghaie and Mohammad Sajadi, 2024). At the same time, it generates new social and regulatory challenges, particularly in relation to digital inequality, labor market restructuring, and the redefinition of human–technology interactions. These tensions require coordinated public policies capable of balancing technological dynamism with social inclusion.

Within this broader framework, digital literacy constitutes a central enabling condition for an inclusive digital transition. Digital literacy is commonly conceptualized as a multidimensional set of competencies—including technical, informational, cognitive, and socio-emotional skills—necessary to access, evaluate, produce, and communicate information in digital environments (Reedy Katharine and Parker, 201AD; Gilster, 1997; Forsyth and Demchak, 2022). Empirical research suggests that higher levels of digital literacy facilitate technological adoption, strengthen innovation capacities, and improve the integration of digital processes in both productive and educational systems. Conversely, deficits in digital literacy deepen

existing social and territorial divides, limiting the potential benefits of digital transformation, particularly in developing contexts. For this reason, skills formation is as critical as infrastructure deployment in digital policy strategies. International frameworks such as DigComp and DigCompEdu explicitly link the development of digital competencies to the evolving demands of labor markets and lifelong learning, positioning digital literacy as a prerequisite for sustainable social and economic development.

In recent years, both international organizations and academia have made efforts to develop synthetic indicators of digital literacy. On the one hand, from the perspective of international organizations, institutions such as the ITU and UNESCO have promoted an international measurement agenda that emphasizes basic computational skills as a core component of digital literacy (Reichert, Pan and Che, 2023). On the other hand, academic research has advanced the construction of synthetic indicators in this field by incorporating more complex dimensions, including technology adoption, emotional factors, cybersecurity, and the ethical dimensions of digital use (Csernoch and Biró, 2015; Chetty *et al.*, 2018; Tinmaz *et al.*, 2022).

Methodology

The primary data source for this study is the National Survey on the Availability and Use of Information and Communication Technologies in Households (ENDUTIH), conducted by Mexico's National Institute of Statistics and Geography (INEGI). ENDUTIH was designed to gather information on the use of and skills related to information and communication technologies (ICTs) among individuals aged six years and older in Mexico. The survey has been conducted annually from 2015 to 2024 (INEGI, 2023, 2024). Importantly, ENDUTIH is statistically representative at the national level, at the level of federal entities (states), and across urban and rural contexts, which ensures the robustness of population-level estimates and enables consistent subnational and territorial analysis.Importantly, ENDUTIH has maintained the comparability of its core variables throughout the entire time series. For the purposes of this study, four cross-sectional waves were selected: 2018, 2020, 2022, and 2024. The objective is to identify the baseline level of computational literacy prior to the COVID-19 pandemic (2018), capture conditions at the onset of the pandemic (2020), and examine potential structural changes in the post-pandemic period (2022 and 2024).

Regarding the selection of variables from ENDUTIH, two types were considered: contextual variables and those required for the construction of the Computational Literacy Index (CLI). On the one hand, the contextual variables include those related to federal entities (states), locality size, and urban–rural classification. In addition, standard demographic variables were incorporated, such as sex, age, educational attainment, and socioeconomic stratum.

On the other hand, the variables used to construct the CLI are the following: use of email, file management, downloading information, use of word processing software,

use of spreadsheets, use of presentation software (e.g., PowerPoint), installation of peripheral devices, database management, and knowledge of programming languages.

Based on the variables selected for the CLI, a Principal Component Analysis (PCA) was estimated in order to obtain a synthetic indicator derived from the nine variables involved. PCA is a widely used statistical technique for the construction of index variables, particularly for the purpose of dimensionality reduction.

For the temporal analysis and to ensure comparability over time, the PCA loadings were estimated using the 2018 wave as the reference year. It is worth noting that the proportion of variance explained by the first component in 2018 is 50%, indicating that the computational literacy construct can be adequately captured by the first principal component.

The factor loadings obtained from the 2018 PCA were subsequently extrapolated to the datasets for the following years. This procedure ensures a common vector space across all periods, thereby guaranteeing temporal comparability of the CLI. In other words, the index for each year is projected onto the same factor structure estimated in the baseline year.

Finally, the CLI was standardized to facilitate interpretation using a min–max rescaling to a 0–100 range. The entire process—including PCA estimation, score prediction, computation of population estimators, and cartographic visualization—was conducted in R using several packages, including *FactoMineR*, *rlang*, *srvyr*, *sf*, and *ggplot2* (Lê, Josse and Husson, 2008a, 2008b; Wickham, 2016; Pebesma, 2018; Henry and Wickham, 2026).

Main Results

The following section presents a set of preliminary descriptive results for the CLI in Mexico over the period analyzed.

Table 1. Percentage of computer, tablet, or laptop use in Mexico, 2018–2024

Year	yes	No	Total
2018	45%	55%	100%
2020	38%	62%	100%
2022	37%	63%	100%
2024	37%	63%	100%

Source: Authors' own elaboration based on ENDUTIH 2018, 2020, 2022, and 2024.

Table 1 presents the percentage evolution of computer use in Mexico over the period analyzed. This dimension is particularly relevant because this question functions as

a filter variable for the skills included in the CLI. In other words, the CLI is calculated only for individuals who reported using a desktop computer, tablet, or laptop.

The table shows a decline of approximately 7 to 8 percentage points from the onset of the pandemic to 2024 relative to 2018. At first glance, this finding appears counterintuitive in light of expectations regarding progress in computational literacy. However, this downward trend can be partially explained by the widespread increase in mobile phone adoption as a substitute for computers in meeting contemporary communication needs.

However, as will be discussed below, computer use enables individuals to develop computational capabilities that mobile phone design does not fully support, such as advanced information processing and the development of a more structured computational cognitive framework.

Table 2. Descriptive statistics of the CLI in Mexico, 2018–2024

Year	q1	q2	mean	q3
2018	38.83	72.77	64.88	92.38
2020	49.17	82.24	68.31	92.38
2022	50.51	82.24	69.87	92.38
2024	50.51	82.32	69.81	92.38

Source: Authors' own elaboration based on ENDUTIH 2018, 2020, 2022, and 2024.

With this in mind, Table 2 presents the population-level descriptive statistics of the CLI. In 2018, the mean CLI score was 64.8 points on a 0–100 scale, indicating that, on average, the population exhibited a medium level of computational literacy in that year. During the pandemic and in the subsequent years, the mean increased by only 4 to 5 points on the same scale.

A closer examination of annual means and medians suggests left-skewed distributions. This pattern implies that a substantial proportion of individuals are concentrated at medium-to-high levels of computational skills. In this regard, the median shows that the 50th percentile increased from 72 points in 2018 to 82 points in 2024, which may be interpreted as a positive development in computational literacy.

However, when this median increase is considered alongside the overall proportion of individuals reporting computer use, it can be inferred that, in absolute terms, the population with computational skills has not necessarily expanded. Finally, the interquartile range declined between 2018 and 2024, indicating a reduction in dispersion and, consequently, a narrowing of the skills gap around the median level of computational literacy.

Table 3. Mean of the CLI by Urban–Rural Context in Mexico, 2018–2024

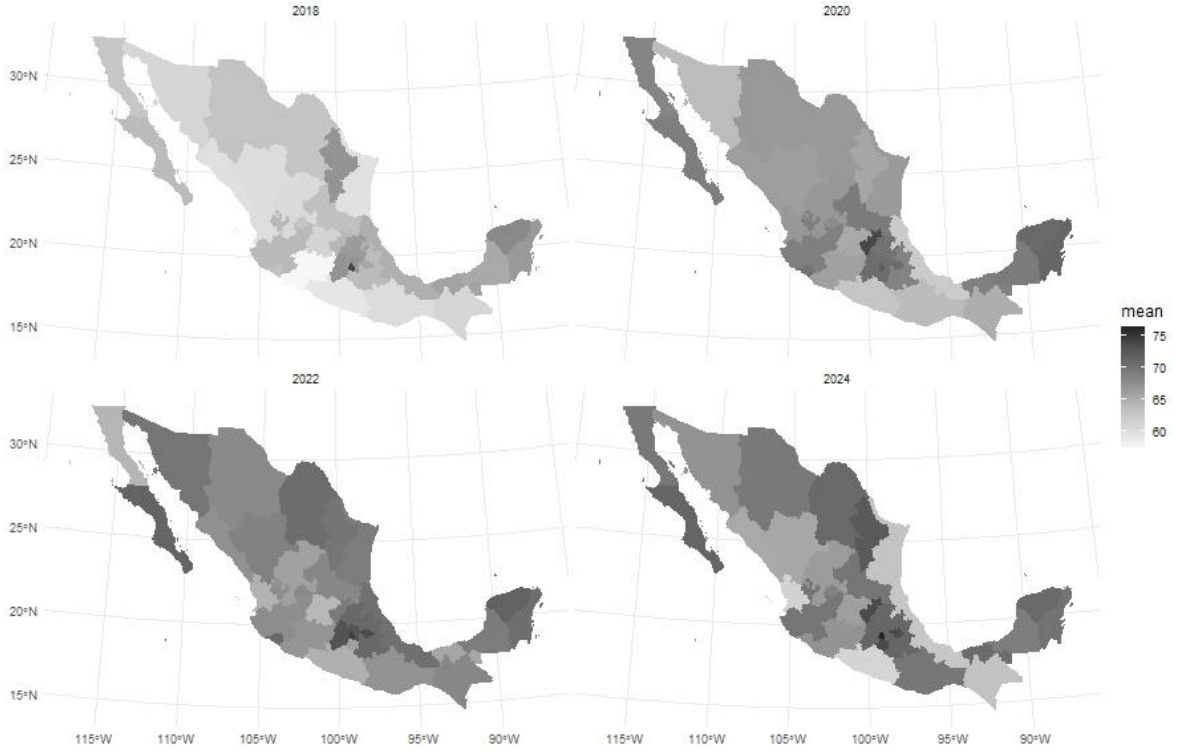
Year	Rural	Urban
2018	55.17	66.32
2020	61.48	69.23
2022	60.45	70.97
2024	59.61	70.84

Source: Authors' own elaboration based on ENDUTIH 2018, 2020, 2022, and 2024.

Table 3 presents the breakdown of the CLI by urban–rural context. The results show that the mean by territorial environment follows a similar pattern to the overall trend: an increase during the pandemic year, followed by a stabilization of the indicator in subsequent years.

Additionally, the mean in urban areas closely mirrors the national average, suggesting that the overall performance of the CLI is largely driven by urban populations. In contrast, although rural areas also experienced a general increase over the period, the indicator remains between 9 and 10 points below the national mean. This persistent gap highlights a structural territorial disparity in computational literacy levels.

Figure 1. Mean of the CLI by Federal Entity, 2018–2024



Source: Authors' own elaboration based on ENDUTIH 2018, 2020, 2022, and 2024.

Figure 1 displays the territorial distribution of the mean CLI for the four years under analysis. At first glance, in 2018 the highest average was observed in Mexico City and, to a lesser extent, in the federal entities that form part of its metropolitan area. Similarly, in that year, the states hosting the country's two largest metropolitan areas—Nuevo León and Jalisco—also stand out. Additionally, the state of Yucatán exhibited a relatively high CLI level in this initial year.

For 2020, a generalized increase in the mean CLI is observed across the national territory, which is consistent with the overall descriptive statistics. In particular, the rise in the average value of the indicator is evident in the central states of the country and in the Yucatán Peninsula.

In this context, during the year marking the onset of the global COVID-19 lockdown, computational skills appear to have developed more strongly—at the subnational level—in Mexico's principal economic regions. In contrast, the states characterized by the highest levels of social inequality, primarily those located in the southern region of the country, exhibited a relative lag in the CLI.

Regarding the post-pandemic years, an increase in the CLI is observed, accompanied by a reconfiguration toward regions that had previously exhibited higher levels of economic development. In both 2022 and 2024, the highest CLI values are concentrated in Mexico City and the states that form part of its metropolitan area. Likewise, Tlaxcala, Querétaro, Nuevo León, and the states of the Yucatán Peninsula emerge as relatively stable regions within the high computational literacy tier.

The remaining federal entities display fluctuations in their CLI levels over the last two years analyzed, without consolidating a clear upward convergence toward the leading regions.

Discussion and Contributions to the Digital Transition and Future Outlook for Mexico

The findings of this study point to two main contributions. On the one hand, the study proposes a synthetic indicator focused on one specific dimension of digital literacy: computational literacy, understood as the use of computational skills. In this regard, the data source generated by Mexico's national statistical institute provides temporal comparability and statistical representativeness, enabling population-level results with clear spatiotemporal traceability.

On the other hand, the study offers a baseline indicator that can serve as a tool for assessing computational skills and anticipating future scenarios within Mexico's ongoing digital transition. Concerning this second contribution, the results open a broader discussion about the role of computational literacy in shaping digital transformation processes, particularly in contexts marked by territorial and social inequalities.

First, an apparent contradiction emerges between the decline in the use of desktop computers, laptops, and tablets and the increase in the CLI. As noted earlier, mobile phones have increasingly positioned themselves as substitute goods for larger and less portable devices such as desktop computers and laptops. However, the widespread use of smartphones limits the development of other critical skills, such as file system management within a digital environment, as well as more advanced data processing and programming capabilities that are essential in the era of Artificial Intelligence.

Second, the results show that, in Mexico, the overall level of the CLI increased between 2018 and 2024, with a substantial jump in 2020 followed by a relative stagnation of the indicator thereafter. Although this trajectory may appear encouraging at first glance, significant territorial disparities persist. The classic urban–rural divide remains evident, placing rural areas at a structural disadvantage. Moreover, at the subnational level, the growth in computational literacy has been reconfigured toward regions with preexisting higher levels of socioeconomic and urban development.

Taken together, these dynamics are critical for understanding Mexico's position within the ongoing global digital transition and for envisioning more socially just futures grounded in the structural elements shaping the digital society.

References

Chetty, K. *et al.* (2018) "Bridging the digital divide: measuring digital literacy," 12(1). Available at: https://doi.org/doi:10.5018/economics-ejournal.ja.2018-23.

Csernoch, M. and Biró, P. (2015) "The Power in Digital Literacy and Algorithmic Skill," *Procedia - Social and Behavioral Sciences*, 174, pp. 550–559. Available at: https://doi.org/https://doi.org/10.1016/j.sbspro.2015.01.705.

Forsyth, A. and Demchak, M. (2022) *Functional Digital Literacy: Improving Email Skills with Adolescents with Intellectual Disabilities*, *ProQuest Dissertations and Theses*. Available at: https://www.proquest.com/dissertations-theses/functional-digital-literacy-improving-email/docview/2771606391/se-2?accountid=26837.

Gilster, P. (1997) *Digital Literacy*. Wiley Computer Pub.

Henry, L. and Wickham, H. (2026) "rlang: Functions for Base Types and Core R and 'Tidyverse' Features." Available at: https://CRAN.R-project.org/package=rlang.

Lê, S., Josse, J. and Husson, F. (2008a) "FactoMineR: A Package for Multivariate Analysis," *Journal of Statistical Software*, 25(1), pp. 1–18. Available at: https://doi.org/10.18637/jss.v025.i01.

Lê, S., Josse, J. and Husson, F. (2008b) "FactoMineR: A Package for Multivariate Analysis," *Journal of Statistical Software*, 25(1), pp. 1–18. Available at: https://doi.org/10.18637/jss.v025.i01.

Oloyede, A.A. *et al.* (2023) "Measuring the impact of the digital economy in developing countries: A systematic review and meta- analysis," *Heliyon*, 9(7), p. e17654. Available at: https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e17654.

Pebesma, E. (2018) "Simple Features for R: Standardized Support for Spatial Vector Data," *The R Journal*, 10(1), pp. 439–446. Available at: https://doi.org/10.32614/RJ-2018-009.

Reedy Katharine and Parker, J. (201AD) *Digital literacy unpacked*. Edited by Reedy Katharine and J. Parker. London: Facet publishing.

Reichert, F., Pan, Q. and Che, L.L. (2023) *Digital literacy assessment*.

Rosário, A. and Dias, J. (2022) “Sustainability and the Digital Transition: A Literature Review,” *Sustainability*, 14(7), p. 4072. Available at: https://doi.org/10.3390/su14074072.

Tinmaz, H. *et al.* (2022) “A systematic review on digital literacy,” *Smart Learning Environments*, 9(1), p. 21. Available at: https://doi.org/10.1186/s40561-022-00204-y.

Wickham, H. (2016) *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. Available at: https://ggplot2.tidyverse.org.

Xia, L., Baghaie, S. and Mohammad Sajadi, S. (2024) “The digital economy: Challenges and opportunities in the new era of technology and electronic communications,” *Ain Shams Engineering Journal*, 15(2), p. 102411. Available at: https://doi.org/https://doi.org/10.1016/j.asej.2023.102411.