

When More Is Not Better: The Nonlinear Association Between Classroom ICT Use and Digital Literacy Across 35 Education Systems

Selmir Hadžić, Azur Kuduzović, Inga Ibralic¹, Haris Memisevic

University of Sarajevo – Faculty of Educational Sciences

Abstract

This study examined the association between students' classroom use of general ICT applications and computer and information literacy (CIL) across 35 education systems participating in ICILS 2023. Jurisdiction-specific weighted regression models were estimated using all five CIL plausible values and 75 jackknife replicate weights while adjusting for socioeconomic background, sex, and age. Jurisdiction-specific coefficients were synthesized using random-effects meta-analysis. Linear models indicated a modest positive association between classroom ICT use and CIL, but quadratic models consistently provided a better fit. The quadratic coefficient was negative in 34 of the 35 jurisdictions, yielding a pooled estimate of -5.66 (95% CI -6.58 to -4.74). Predicted CIL increased with classroom ICT use to approximately the midpoint of the international scale, after which gains diminished and CIL gradually declined. This nonlinear pattern was remarkably consistent across education systems and did not vary meaningfully by socioeconomic background. These findings suggest that the educational value of classroom ICT use depends not only on how often digital technologies are used, but also on how they are integrated into teaching and learning.

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¹ Corresponding author's email: ibralic.inga@gmail.com

Introduction

Computer and information literacy (CIL) has become fundamental to learning, employment, social participation, and informed citizenship in digital societies. As information and communication technologies (ICT) transform communication, work, healthcare, commerce, and education, individuals must be able not only to access digital technologies but also to locate, evaluate, create, and communicate information effectively in digital environments (Chinonso et al., 2023). Education systems have therefore increasingly emphasized students' digital competencies as essential for participation in the twenty-first century and for lifelong learning (Reddy et al., 2020). Meeting this goal requires effective pedagogical integration of ICT because its educational value depends less on availability than on how it supports learning (McKnight et al., 2016; Okoye et al., 2022; Santos & Serpa, 2017).

The International Computer and Information Literacy Study (ICILS), conducted by the International Association for the Evaluation of Educational Achievement (IEA), is the principal international assessment of CIL (Fraillon et al., 2019). The ICILS framework defines CIL as the ability to use digital technologies to investigate, create, and communicate information for effective participation in school, work, and society (Fraillon & Duckworth, 2024). In addition to an authentic computer-based assessment of achievement, ICILS collects extensive contextual data from students, teachers, and schools, including information about ICT use. These data provide a valuable basis for examining factors associated with digital competence across education systems (Fraillon et al., 2020). Schools seek to develop CIL partly by integrating ICT into classroom instruction (Cabellos et al., 2023; Drossel et al., 2020). Such integration can foster higher-order thinking by enabling students to investigate, solve complex problems, and collaborate in diverse environments (Eger et al., 2018). It can also create authentic opportunities to locate, evaluate, organize, create, and communicate information—the core competencies encompassed by CIL (Perez-Sanagustin et al., 2016; Tondeur et al., 2015). Yet educational benefits are not determined solely by access or frequency; they depend on how digital technologies are integrated into pedagogy and aligned with instructional objectives (Bernard et al., 2023). Within this broader context, students' reported classroom ICT use offers one indicator of their everyday exposure to technology-supported learning.

Research nevertheless cautions that technology does not improve learning by itself. Outcomes depend on whether digital tools are embedded in meaningful activities that promote inquiry, collaboration, communication, and knowledge construction (McKnight et al., 2016). Accordingly, digital technologies are better understood as context-dependent instructional tools whose effects reflect how they are used, not simply their presence or frequency (Dontre, 2021). Students who report similar levels of use may therefore encounter markedly different practices, depending on teachers' pedagogical approaches and instructional purposes. Frequency measures are thus, at best, indirect proxies for technology-supported learning. This limitation raises the question of whether a simple linear association adequately describes the relationship between classroom ICT use and CIL. Evidence from 22 OECD countries supports considering nonlinearity: Gorjón and Osés (2023) reported an inverted U-shaped association between school ICT use and mathematics achievement, suggesting that outcomes may not improve proportionally as use becomes more frequent.

Empirical evidence on classroom ICT use and CIL remains mixed. Some studies report positive associations, suggesting that students who participate more often in ICT-supported activities tend to demonstrate higher CIL (Mirazchiyski, 2025; Rohatgi et al., 2016). A recent meta-analysis of experimental and quasi-experimental research likewise found that technology-supported learning generally improved digital literacy, although effect sizes varied substantially across contexts (Wang & Fan, 2025). These benefits have typically been attributed

to opportunities to practise information management, communication, collaboration, and digital problem solving.

Other research points to weaker or more complex patterns. Hatlevik et al. (2018), for example, found that the relationship between school ICT use and CIL was less straightforward than commonly assumed. Using ICILS 2013 data, Bundsgaard and Gerick (2017) observed higher CIL at intermediate rather than very low or very high levels of computer use. More recently, Caponera et al. (2026) argued that frequency alone is an insufficient indicator because different forms of ICT engagement may have markedly different implications for learning. Taken together, this evidence suggests that the benefits associated with classroom technology use may not increase linearly with frequency.

A plausible explanation is that frequency does not capture the pedagogical quality, instructional purpose, or cognitive demands of technology-supported activities. At similar reported frequencies, students may engage in tasks ranging from routine information retrieval to collaborative problem solving and knowledge creation. More frequent use may therefore not yield proportional gains in CIL.

Most previous studies have nevertheless estimated linear associations between classroom ICT use and CIL, thereby assuming a constant change in digital competence across the range of use. Few have tested this assumption across education systems, despite theoretical grounds for expecting diminishing returns at higher frequencies. Given continuing global investment in school digitalization, determining whether the association is linear or nonlinear has implications for policy and for the pedagogically effective integration of ICT.

The present study extends this literature in three ways. First, it tests whether a nonlinear model represents the association between classroom ICT use and CIL better than a linear model. Second, it evaluates the consistency of that association across 35 education systems rather than within a single national context. Third, it combines jurisdiction-specific polynomial regression with random-effects meta-analysis to provide a cross-national synthesis of nonlinear associations, an approach largely absent from previous ICILS research. Accordingly, we examined the association between students' classroom use of general ICT applications and CIL across the 35 education systems participating in ICILS 2023. We specifically assessed whether a nonlinear model provided a better representation after adjustment for socioeconomic background, sex, and age, and used random-effects meta-analysis to evaluate the consistency of jurisdiction-specific coefficients.

Methods

Participants

Data came from the 2023 cycle of the International Computer and Information Literacy Study (ICILS 2023), a cross-sectional international large-scale assessment coordinated by IEA. The target population comprised students in the eighth year of schooling, counted from the first year of ISCED level 1, provided that the mean age in that grade was at least 13.5 years at assessment. In most education systems, this corresponded to Grade 8 and an age of approximately 14 years (Fraillon et al., 2026). The analysis included all 35 public-use student files: Austria, Azerbaijan, Belgium (Flemish), Bosnia and Herzegovina, Chile, Chinese Taipei, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Kazakhstan, Republic of Korea, Kosovo, Latvia, Luxembourg, Malta, Netherlands, Norway, Oman, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Spain, Sweden, United States, Uruguay, and North Rhine-Westphalia (Germany). North Rhine-Westphalia, an IEA benchmarking (subnational) participant, was retained as a separate jurisdiction in the primary analyses and excluded in a sensitivity analysis.

Before analysis-specific exclusions, the 35 source files contained 135,615 student records. Complete-case samples for the primary models totalled 123,517 and ranged from 1,088 to 10,822 students per jurisdiction (median = 3,083). Jurisdiction-specific loss relative to the source file ranged from 0.84% to 22.78% (median = 8.38%); only Azerbaijan (21.22%) and North Rhine-Westphalia (22.78%) exceeded 20%. No additional substantive eligibility criterion was imposed. The analysis required complete, valid data for all five CIL plausible values, the final and 75 replicate weights, and all variables in the fitted model. This study was a secondary analysis of de-identified, publicly available data.

Procedure

ICILS 2023 used a cross-sectional, stratified two-stage probability sampling design. Within each jurisdiction, schools were selected with probability proportional to the number of target-grade students. One or more intact target-grade classes were then randomly selected, and all students in those classes were invited to participate (Fraillon et al., 2026). Students completed a computer-based CIL assessment and a computer-administered contextual questionnaire under standardized international procedures. National research centres translated and adapted the materials according to international guidelines to maintain conceptual equivalence across jurisdictions (Fraillon et al., 2026; Meyer et al., 2025).

Sampling, administration, quality assurance, and data processing followed standardized IEA procedures. The public-use international database provides a final sampling weight and 75 jackknife repeated replication (JRR) weights for unbiased estimation and appropriate variance calculation under the complex sampling design (Meyer et al., 2025). Data were anonymized before public release, and national research centres implemented ethical and consent procedures in accordance with national regulations.

Instruments

Students' use of general ICT applications in class (S_GENCLASS). The ICILS 2023 derived scale S_GENCLASS measured how often students used general ICT applications during lessons. Four self-reported items covered (a) word-processing software, (b) presentation software, (c) spreadsheets, and (d) computer-based information resources (e.g., websites, wikis, and online encyclopedias) during the current school year. Responses ranged from 1 = *never* to 4 = *in every or almost every lesson*. IEA constructed the scale with a Rasch partial credit model and estimated individual scores as Warm weighted-likelihood estimates (WLEs), standardized to an international mean of 50 and standard deviation of 10. Higher scores indicate more frequent classroom use of these applications. Reported international reliability was .803 (Cronbach's α).

Socioeconomic background (NISB). The ICILS 2023 National Index of Socioeconomic Background (NISB) is a jurisdiction-specific composite of three indicators: highest parental occupational status (S_HISEI), highest parental educational attainment (S_HISCED), and home literacy resources measured by books in the home (S_HOMLIT). The index was constructed separately within each jurisdiction through principal component analysis of the correlations among these indicators. When one component was missing, ICILS imputed it from the other two within the national sample before deriving the index. Scores were standardized within jurisdictions to a mean of 0 and standard deviation of 1; a one-unit difference therefore represents one jurisdiction-specific standard deviation in relative socioeconomic background. Higher scores indicate greater socioeconomic advantage.

Statistical Analysis

Analyses were conducted separately for each of the 35 jurisdictions. CIL achievement was represented by all five plausible values (PV1CIL–PV5CIL). Every regression model

incorporated the final student sampling weight (TOTWGTS) and 75 JRR weights (SRWGT01–SRWGT75) to account for the complex sampling design and obtain appropriate variance estimates. Complete-case analysis included observations with valid values for every variable in the fitted model.

S_GENCLASS was centred at the international scale mean of 50 and divided by 10, so the regression coefficients represent a 10-point difference on the ICILS scale. In the polynomial model, the linear coefficient therefore represents the local slope at S_GENCLASS = 50, and the quadratic term is the square of the centred variable. NISB remained on its original jurisdiction-standardized scale. Student age (S_AGE) was centred at the jurisdiction-specific weighted mean, and sex (S_SEX) was coded 0 = boy and 1 = girl.

Three hierarchical weighted regression models were estimated on a common analytic sample. Model 1 included socioeconomic background, sex, and age (CIL ~ NISB + S_SEX + S_AGE). Model 2 added S_GENCLASS (CIL ~ NISB + S_GENCLASS + S_SEX + S_AGE), and Model 3 added its quadratic term (CIL ~ NISB + S_GENCLASS + S_GENCLASS² + S_SEX + S_AGE). Consistent with the hierarchical principle of polynomial regression, the linear term was retained in Model 3. Weighted coefficients of determination (R²) were calculated for each plausible value, averaged within jurisdictions, and summarized descriptively across jurisdictions. All analyses were conducted in R (R Core Team, 2021).

Results

Table 1 summarizes the analytic samples in the 35 ICILS 2023 jurisdictions. Sample sizes ranged from 1,088 to 10,822 students (median = 3,083). Weighted mean CIL scores ranged from 342.39 to 544.06, and weighted mean S_GENCLASS scores from 44.31 to 62.34. Complete-case exclusion ranged from 0.84% to 22.78% (median = 8.38%).

Table 1.

Descriptive characteristics of the 35 ICILS 2023 jurisdictions.

Measure	Median	Minimum	Maximum
Analytic sample size	3083	1088	10822
Weighted mean CIL	498.91	342.39	544.06
Weighted mean S_GENCLASS	49.68	44.31	62.34
Weighted SD S_GENCLASS	9.20	6.96	11.96
Complete-case exclusion (%)	8.38	0.84	22.78

Hierarchical regression models

Three hierarchical weighted regression models were estimated separately within each jurisdiction to compare linear and nonlinear representations of the association between classroom ICT use and CIL. Model 1 included NISB, sex, and age; Model 2 added S_GENCLASS; and Model 3 included both its linear and quadratic terms. As Table 2 shows, the median weighted coefficient of determination increased from .131 in Model 1 to .140 in Model 2 and .153 in Model 3, indicating a modest but consistent improvement in fit across jurisdictions.

Table 2.

Hierarchical regression models predicting computer and information literacy across ICILS 2023 jurisdictions.

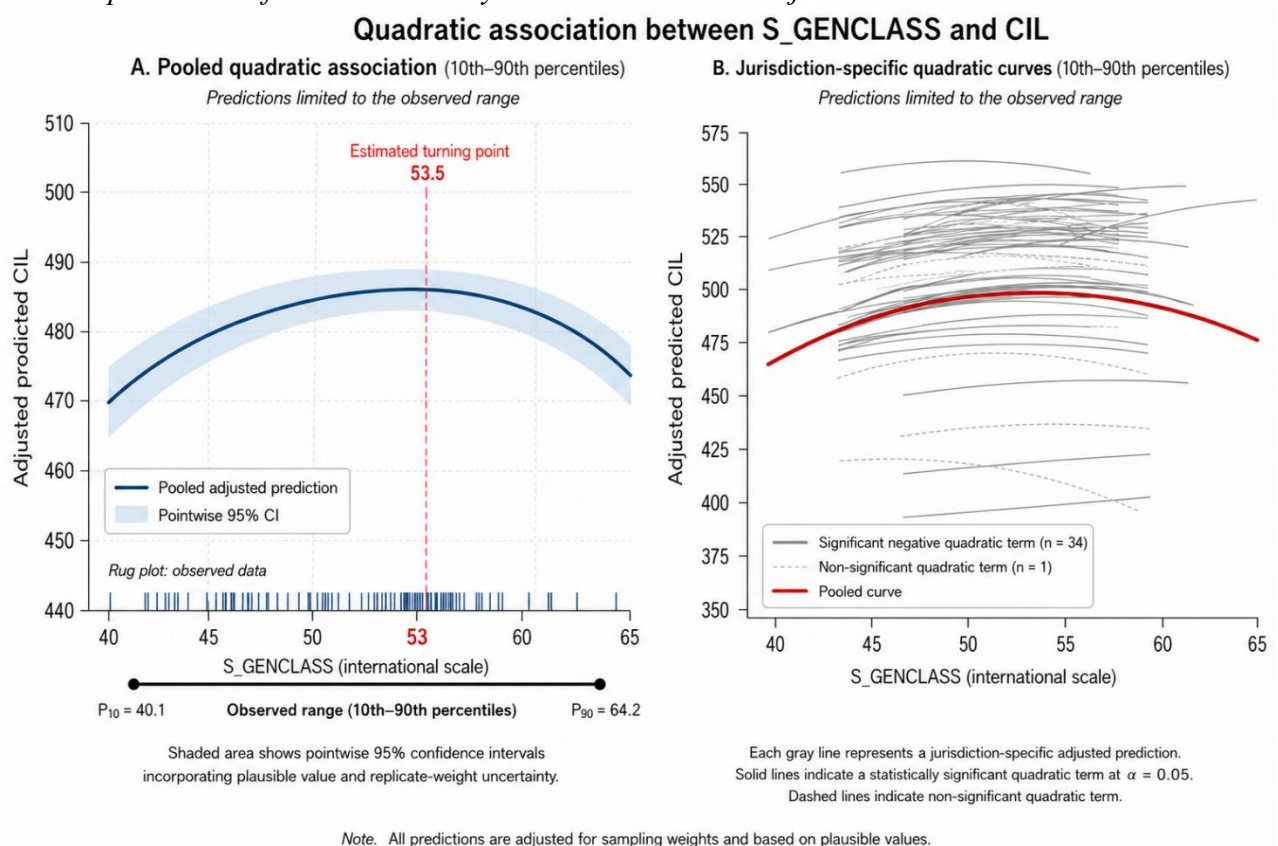
Model	Predictors	Median weighted R ²
1	NISB + sex + age	.131
2	Model 1 + S_GENCLASS	.140
3	Model 2 + S_GENCLASS ²	.153

Nonlinear association between classroom ICT use and CIL

In the linear model, S_GENCLASS was positively associated with CIL ($B = 4.74$ per 10 scale points, 95% CI [3.15, 6.34]); however, this coefficient summarizes the average association across the observed range. Adding the quadratic term increased the median weighted R² from .140 to .153 across jurisdictions, indicating better model fit (Table 2).

The quadratic coefficient was negative in 34 of the 35 education systems, with a pooled random-effects estimate of -5.66 CIL points per squared 10-point unit (95% CI $[-6.58, -4.74]$). Figure 1 presents the pooled nonlinear association together with the jurisdiction-specific fitted curves.

Figure 1. Pooled and jurisdiction-specific nonlinear associations between classroom ICT use and computer and information literacy across 35 ICILS 2023 jurisdictions.

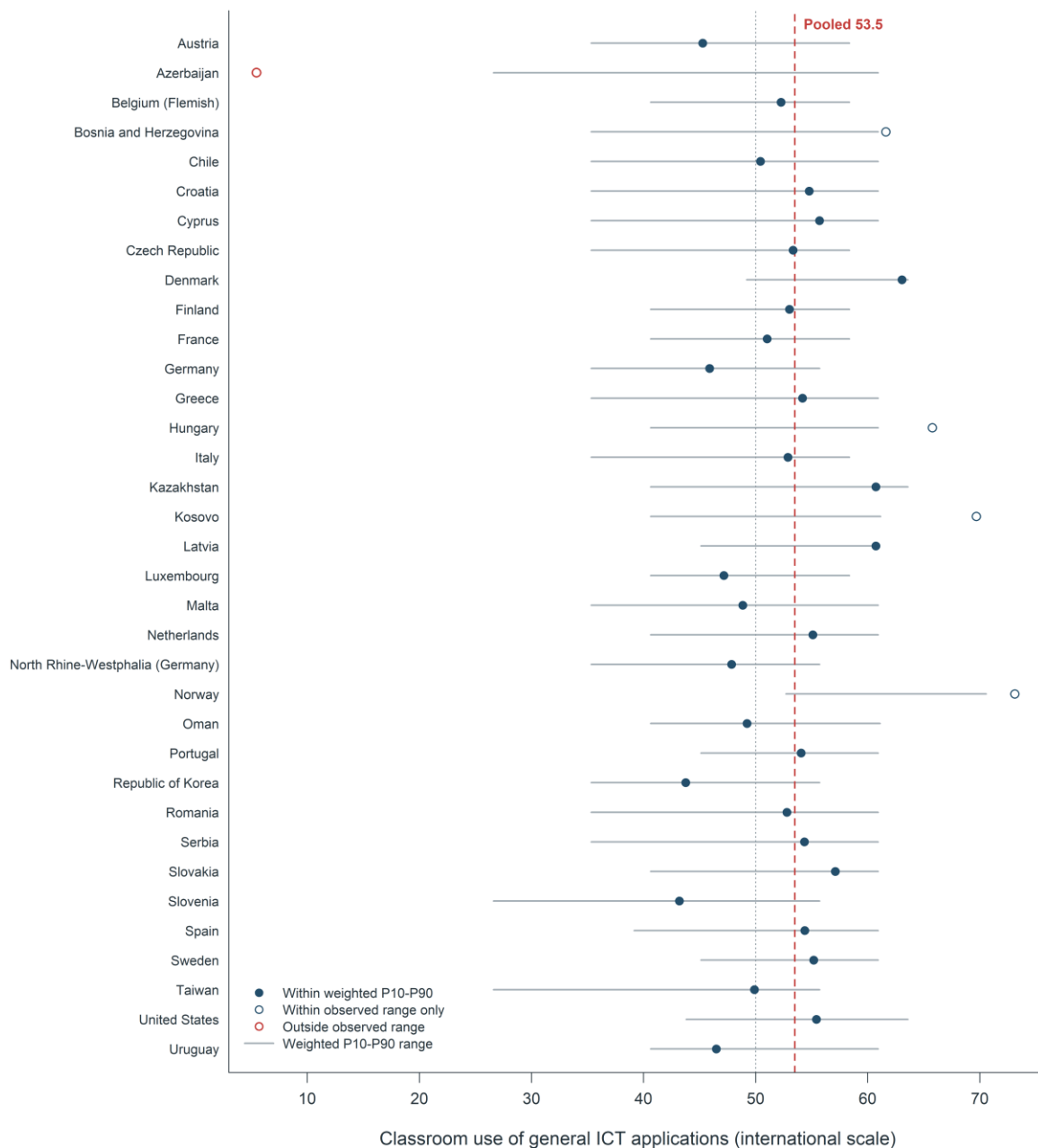


As Figure 1, Panel A, shows, predicted CIL increased with classroom use of general ICT applications before reaching a plateau and then declining slightly at the highest reported levels. Although the magnitude of the association varied across jurisdictions, Panel B indicates that the concave functional form was consistently observed across education systems.

Figure 2 summarizes the estimated turning points together with the jurisdiction-specific weighted 10th–90th percentile ranges of classroom ICT use. Most turning points clustered closely around the pooled estimate, illustrating the remarkable consistency of the nonlinear association across education systems.

Figure 2.

Estimated turning points in the jurisdiction-specific quadratic associations between classroom use of general ICT applications and computer and information literacy across 35 ICILS 2023 jurisdictions.



Estimated turning points in the jurisdiction-specific quadratic associations between classroom use of general ICT applications and computer and information literacy across 35 ICILS 2023 jurisdictions.

Robustness analyses

The findings were robust across the prespecified sensitivity analyses. Excluding the two jurisdictions with more than 20% complete-case loss (Azerbaijan and North Rhine-Westphalia), restricting the sample to national jurisdictions, and omitting sex and age as covariates produced negligible changes in the pooled NISB and quadratic S_GENCLASS coefficients. Leave-one-jurisdiction-out analyses likewise indicated that no jurisdiction unduly influenced the pooled estimates. The direction and statistical inference of the main findings were unchanged in every sensitivity analysis. Additional models found no meaningful interaction between socioeconomic background and S_GENCLASS, indicating that the nonlinear association was broadly consistent across socioeconomic groups.

Discussion

Across the 35 ICILS 2023 jurisdictions, a quadratic specification described the association between students' classroom use of general ICT applications and CIL better than a simple linear model. Whereas the linear model indicated a modest positive association after adjustment for socioeconomic background, sex, and age, the polynomial model revealed a concave pattern: 34 jurisdictions had a negative quadratic coefficient, and model fit improved when the quadratic term was added. The results therefore qualify the positive average association implied by a linear specification and extend research documenting heterogeneous relationships between ICT use and digital competence (Lang et al., 2023; Rafiq-uz-Zaman, 2023; Tinmaz et al., 2022).

This pattern should not be interpreted as indicating that greater classroom use of digital technologies is inherently beneficial or detrimental. Previous reviews and large-scale studies have similarly concluded that the educational effects of ICT use are heterogeneous and depend more on how technologies are implemented than on how frequently they are used (Valverde-Berrocso et al., 2022; Yeung et al., 2021). The positive association with CIL was strongest at low to moderate levels of reported use and weakened progressively higher on the scale. Although its magnitude differed across jurisdictions, the direction of curvature was highly consistent and was not attributable to a small group of influential education systems. Moreover, the negligible interaction with socioeconomic background suggests that the pattern was broadly comparable across socioeconomic groups.

Interpretation must remain anchored to the construct measured by S_GENCLASS. The scale records how frequently students reported using word-processing software, presentation software, spreadsheets, and computer-based information resources during lessons (Rožman et al., 2025). It does not assess the pedagogical purpose of those activities, their cognitive complexity, the quality of teacher guidance, or the effectiveness of instruction (Fraillon & Duckworth, 2024; Gebhardt et al., 2019). The construct is therefore frequency of use, not the quality of ICT-supported teaching.

This distinction offers one plausible account of the nonlinear association. At low levels of reported use, an increase may distinguish students with few opportunities to engage with digital technologies from those who use them often enough to practise searching for information, organizing content, preparing documents, presenting ideas, and working with tabular data. Because these activities overlap with competencies assessed by ICILS, a positive association with CIL is theoretically plausible. Prior studies have similarly linked classroom ICT use, ICT self-efficacy, and CIL, while recognizing that these are distinct constructs (Hatlevik et al., 2018; Mirazchiyski, 2025; Rohatgi et al., 2016). Caponera et al. (2026) further identified students who combined frequent ICT use with relatively low digital competence,

illustrating why greater frequency need not correspond to stronger skills or more favorable educational outcomes.

Beyond approximately 53 points on the international scale, frequency alone may become an increasingly poor indicator of differences in students' learning experiences. Similar levels of reported use can encompass markedly different learning activities. Word-processing software, for example, may support cognitively demanding activities such as iterative writing, collaborative revision, and critical evaluation of ideas, but it may equally be used for routine tasks such as copying notes, completing worksheets, or formatting assignments (Harris et al., 2009; Koehler & Mishra, 2013). Presentation software may facilitate communication and collaborative knowledge construction, but it may also be used primarily to support teacher-directed instruction. Comparable variation applies to spreadsheets and online information resources, whose educational value depends on how they are integrated into teaching and learning rather than on the technologies themselves (McKnight et al., 2016; Bernard et al., 2023). Because S_GENCLASS is constructed as a single frequency-based indicator summarizing students' reported use of several categories of general ICT applications (Chen et al., 2025; Mirazchiyski, 2025), it cannot distinguish between cognitively demanding digital learning activities and routine or repetitive uses of the same technologies. This interpretation is also consistent with the findings of Caponera et al. (2026), who reported that ICT use for study purposes was not independently associated with digital literacy or mathematics achievement after accounting for digital competence and concluded that the type of activity is more informative than frequency alone.

The plateau and slight decline beyond the estimated turning point should therefore not be read as evidence that technology “stops working” or that additional classroom use is necessarily counterproductive. Instead, at moderate to high frequencies, S_GENCLASS may become an increasingly imprecise proxy for the instructional processes most relevant to CIL development. Frequent classroom use of general ICT applications may reflect inquiry-oriented learning, but it may equally represent routine document production, teacher-centred instruction, or learning activities with relatively limited cognitive demand (Abedi, 2024; Harris et al., 2009). The curvature may thus reflect growing heterogeneity in instructional practice rather than a decline in the educational value of technology itself.

Viewed in this light, the findings help reconcile earlier evidence. Positive linear associations may primarily reflect the ascending part of the curve or contexts in which more frequent use corresponds closely to richer learning opportunities (Rohatgi et al., 2016; Sibagariang et al., 2023). Weaker or more complex associations, by contrast, are compatible with variation in how digital technologies are integrated into instruction (Hatlevik et al., 2018). Bundsgaard and Gerick (2017) similarly linked different patterns of computer use to different CIL profiles, underscoring the importance of configuration and purpose as well as frequency. Wang and Fan's (2025) meta-analysis also found that the effectiveness of technology-supported learning varied substantially with context and implementation. Collectively, this literature supports interpreting frequency indicators as partial representations of students' digital learning experiences.

The present findings also have implications for educational policy. Educational investments in school digitalization have largely focused on expanding access to digital technologies and increasing opportunities for their use in classroom instruction (Conrads et al., 2017). However, the present results suggest that increasing the frequency of classroom ICT use alone is unlikely to constitute a sufficient policy target. Rather, greater emphasis should be placed on ensuring that digital technologies are integrated into pedagogically meaningful, cognitively engaging, and instructionally effective learning activities (Bernard et al., 2023). This interpretation is consistent with recent evidence showing that the quality of technology

integration explains substantially more variance in students' digital competencies than the frequency of technology use itself (Consoli et al., 2025). Consequently, the central question for educational policy is not simply how often students use digital technologies during classroom instruction, but how those technologies are used to support higher-order thinking, knowledge construction, collaboration, and problem solving. Alternative explanations remain possible. Students with higher prior computer and information literacy may receive different ICT-related learning opportunities; teachers may adapt classroom technology use according to students' existing competence or curricular requirements; and differences in school infrastructure, pedagogical practices, and broader school contexts may influence both classroom ICT use and CIL (Schmid & Petko, 2019; Timotheou et al., 2023). These alternative mechanisms should therefore be considered when interpreting the observed nonlinear association.

Several limitations qualify the findings. First, the cross-sectional ICILS design precludes causal inference and cannot establish the temporal ordering of classroom ICT use and CIL (Aydin, 2022). Second, S_GENCLASS is self-reported and measures the frequency of using general applications during lessons, not pedagogical quality, instructional purpose, or the cognitive demands of technology-supported learning. Students with similar scores may therefore have experienced markedly different instruction. Third, although the models adjusted for socioeconomic background, sex, and age, they did not include other potentially relevant factors, such as teacher practices, school ICT infrastructure, curriculum implementation, or students' prior digital competence.

Taken together, the results show that a linear model incompletely describes the association between classroom ICT use and CIL; they do not identify an optimal frequency of use. Future research should move beyond exposure measures by combining large-scale assessment data with direct indicators of instructional quality and pedagogical practice. Longitudinal and intervention designs are also needed to clarify the mechanisms through which technology use may contribute to students' digital competence.

Conclusion

Overall, the frequency of classroom ICT use is an incomplete indicator of digital learning opportunities. Across diverse education systems, moderate increases in the use of general ICT applications were associated with higher CIL, but the association weakened progressively at higher frequencies. The findings therefore support moving beyond exposure measures toward richer indicators of the pedagogical quality, instructional purpose, and cognitive demands of technology-supported learning.

Conflict of interest

None.

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