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Digital literacy and ICT use: key predictors of mathematics achievement in schoolchildren

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Abstract
Despite the widespread integration of ICT into education, research linking students' everyday ICT use to mathematics performance has yielded inconsistent results. A key gap in the existing literature is the limited attention to factors such as actual digital literacy and the specific purposes for which ICT is used. This study addresses this gap by examining the relationship between students' performance in the International Computer and Information Literacy Study (ICILS) and their results in the national mathematics assessment. The analysis is based on data from 2309 students who participated in the national mathematics assessment in fifth grade and again took both the ICILS and the national mathematics assessment in eighth grade. A structural equation model incorporating the study variables explained 43% of the variance in students' mathematics scores. After controlling for socioeconomic status (SES) and prior mathematics achievement, the findings indicate that digital literacy significantly contributes to mathematics performance. Specifically, students with higher ICILS scores at the beginning of the school year achieved better mathematics outcomes by the end. In contrast, the frequency of ICT use for study or social communication was not linked to digital literacy or improved mathematics performance. These findings suggest that enhancing students' ICT skills is a promising strategy for improving mathematics performance. The study highlights that growing up with digital devices does not automatically equate to sophisticated digital skills. It supports the argument that the focus of the "digital divide" should shift toward differences in the development of digital skills, rather than merely access to technology.

Keywords Information and communication technology (ICT) · Digital literacy · Mathematics achievement · Structural equation modeling (SEM) · IEA ICILS

Introduction

Information and communication technologies (ICTs) are widely recognized as promising tools for enhancing academic performance across various disciplines. One field where ICT use is believed to particularly benefit learning is mathematics, a subject fundamental to

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technological advancements and more extensively supported by technological tools than many other fields (Aydin, 2005). According to the American National Council of Teachers of Mathematics (NCTM, 2023), ICTs can significantly support both educators and learners in the field of mathematics by facilitating calculations, making connections, visualizing data, identifying key concepts, synthesizing information, and promoting problem-solving skills (Joshi, 2017; Verschaffel et al., 2019). Moreover, the integration of technology and digital tools into mathematics education plays an increasingly important role in shaping mathematical literacy (Cirneanu et al., 2024; Zhang et al., 2017).

One of the primary concerns for parents and educational policymakers is the persistence of children's difficulties in mathematics. In this line, ICT use in early school years could be seen as a potential aid to overcome such difficulties that often continue throughout children's academic careers, potentially hindering their performance in higher-level math courses. Early struggles in mathematics can have lasting consequences, highlighting the need for educators to understand both the potential benefits and pitfalls of ICT use in mathematics learning. Investigating this relationship is fundamental for developing effective strategies to support student learning (Clements & Sarama, 2016; De Witte & Rogge, 2014; Jordan & Mitchell, 2009; Skryabin et al., 2015).

Despite the widespread integration of ICT into educational settings and its recognition as a powerful tool for education, research linking students' everyday use of ICT to their performance in mathematics has yielded inconsistent results. Several studies have explored this relationship, with mixed findings. Some studies have found a positive relationship between frequent ICT use and math performance (Chiao & Chiu, 2018; Delen & Bulut, 2011; Song & Kang, 2012; Zeng, 2025). In contrast, other studies have reported negative outcomes (e.g., Ayieko et al., 2017; Courtney et al., 2022) or no significant relationships (e.g., Fernández-Gutiérrez et al., 2020; Juhaňák et al., 2018; Wittwer & Senkbeil, 2008). This inconsistency is further supported by Odell et al.'s (2020) scoping review, which identified mixed positive, negative, and null relationships depending on various contextual factors.

Nevertheless, the actual association between ICT use and mathematics achievement remains a subject of ongoing research. Key issues that remain underexplored are the role of students' purpose for using ICT in daily life and their actual digital literacy, as measured by objective assessments. Previous studies have relied on ICT usage frequency as a proxy for digital competence, without accounting for students' actual digital literacy. In addition, several studies overlook the critical variable of students' purpose for using ICT, which may range from social networking to using educational apps. Furthermore, the relationship between ICT use and mathematics performance has been studied in isolation, without considering students' prior mathematics knowledge and performance.

Before exploring the effects of ICT-based interventions on mathematics education, it is crucial to further understand students' purposes for using ICT in their daily lives, how these purposes relate to mathematics achievement, and the extent to which mathematics achievement aligns with objectively measured digital literacy. Gaining a clearer understanding of these relationships is essential for evaluating the potential of acquiring specific ICT competencies to support mathematics learning. This is particularly relevant in light of research showing that ICT is associated with school performance, though this relationship weakens once ICT usage exceeds a certain threshold (Bhutoria & Aljabri, 2022).

Moreover, the significant disparities in mathematics performance related to socioeconomic status, cultural background, and gender—issues that continue to be debated in the literature (Else-Quest et al., 2010; Geist & King, 2008; Girelli, 2023; Gustafsson et al., 2018; Li et al., 2021; Steegh et al., 2019)—underscore the importance of considering how

these factors relate to ICT use, digital literacy, and mathematics performance. Investigating the potential role of digital literacy in addressing these disparities could provide valuable insights into how ICT can be leveraged to promote more equitable learning outcomes in mathematics. Although these studies shed some light on the role of ICT use purpose in relation to mathematics achievement, this relationship remains largely unexplored, particularly in the context of students' prior mathematical performance and formal ICT education.

To address these mixed findings, the present study takes a novel approach to examining the relationship between ICT and mathematics performance by addressing variables that have been overlooked in previous research. Unlike many previous studies that do not consider the purpose of ICT use or rely solely on self-reported use or perceived ICT competence, this study investigates how students' purpose for using ICT (educational versus non-educational) relates to their mathematics performance, using objective measures of digital literacy. Additionally, it accounts for students' prior mathematics performance, allowing for a nuanced analysis of the relationship between ICT use, digital literacy, and learning outcomes over time. Prior research has explored the correlation between ICT use purpose and mathematics achievement at a single time point, without considering how the purpose of ICT use may relate to math performance in the context of students' prior mathematics knowledge, prior to the formal integration of ICT into the curriculum. For example, in the Italian education system, the learning objectives for the end of the fifth grade do not require students to have developed specific computer skills or familiarity with ICT, as these are formally included starting from grade six (Italian Ministry of Education, University and Research, 2012).

Using data from a large, representative sample of Italian students who participated in the National Institute for the Evaluation of Educational System (INVALSI) mathematics assessments in the fifth and eighth grades, as well as the ICILS in the eighth grade, this study explores three key research questions:

- RQ1. *What specific types of daily ICT use are related to mathematics performance in school-aged children?* In other words, is self-reported ICT use for study purposes only associated with mathematics outcomes, or is ICT use for non-educational purposes also related to mathematics learning?
- RQ2. *Does objectively measured digital literacy, rather than simply self-reported ICT usage frequency, correlate with improvements in mathematics performance from fifth to eighth grade?*
- RQ3. *Does digital literacy play a role in mitigating mathematics learning disparities related to gender and/or socioeconomic status?*

Research background and hypothesis development

ICT purpose use and mathematics learning

The relationship between ICT use and school performance varies significantly depending on the purpose of ICT engagement (Falck et al., 2018; Petko et al., 2017; Skryabin et al., 2015). Students utilize digital devices for a wide range of purposes, from leisure activities, such as chatting online, playing games, or watching movies, to educational tasks, including researching information, downloading class materials, or enhancing learning through educational software. When these different uses are considered, the relationship between ICT

use and mathematics achievement becomes clearer. Liang (2025) and colleagues' network analysis showed that students' performance in reading, math, and science is closely linked to ICT use in various contexts. Meggiolaro (2018), using data from the Programme for International Student Assessment (PISA) 2012, found a positive association between ICT use and mathematics achievement only when computers were used for educational purposes, regardless of whether this use occurred at home or at school. In contrast, higher ICT use for social networking was negatively associated with mathematics achievement (Posso, 2016), as well as the earlier age at which students began using ICT (Navarro-Martinez & Peña-Acuña, 2022). More recently, Li et al. (2025) conducted a meta-analysis showing a medium positive correlation between students' academic achievement and digital literacy that was measured by self-reported not objective measures in the great majority of the studies.

Digital literacy and ICT use

A critical issue in the existing literature is that previous studies assessing ICT use frequency and self-reported competency in ICT use have not accounted for the actual digital literacy of students. Digital literacy is a critical concept in educational settings, defined as the ability to effectively use technology tools to process, manage, and evaluate information, as well as to communicate (Ainley et al., 2007; Fraillon et al., 2019a; Somerville et al., 2008). Simply spending time on ICT activities does not necessarily correlate with students' digital literacy. This was demonstrated by Murray and Pérez (2014), who administered a digital literacy task to graduating seniors, assuming they would possess high digital competence. However, the results revealed that approximately 70% of the students failed the test. This highlights the need for "objective" measures of digital literacy, based on standardized and validated tasks. For example, Pagani et al. (2016) showed that the Informational Internet skills, measured by an objective test, were highly correlated ($r = 0.55$) with mathematics achievement in upper secondary school.

To address this gap, the International Association for the Evaluation of Educational Achievement (IEA) developed the International Computer and Information Literacy (CIL) test to assess the digital literacy of eighth-grade students. Research using CIL tasks has shown that "digital natives" are not necessarily digital experts. Simply growing up using digital devices does not automatically foster sophisticated digital skills. Moreover, a self-reported high frequency of ICT use does not correlate with high performance in digital literacy tasks (Fraillon et al., 2019b). This gap underscores the importance of focusing on students' actual digital literacy rather than relying solely on self-reported ICT usage frequency and self-reported digital literacy.

Gender and socioeconomic status

The relationship between socioeconomic status (SES), gender, and mathematics achievement continues to be a key topic of focus and debate in academic literature (Alvarez-Garcia et al., 2024; Else-Quest et al., 2010; Geist & King, 2008; Gustafsson et al., 2018; Hu et al., 2018; Li et al., 2021; Mejía-Rodríguez et al., 2021; Steegh et al., 2019). A high SES was found to be consistently related to better mathematics performance across all studies. As Tan (2024) highlights in his recent review, SES is a crucial predictor of students' learning outcomes, especially in mathematics. With respect to gender, differences in mathematics

achievement, which favor boys, result from the complex interactions of individual, social, and cultural factors (Alvarez-Garcia et al., 2024; Girelli, 2023).

Gender and SES differences also represent a central theme in ICT literacy research. In their meta-analysis, Siddiq and Scherer (2019) found that girls outperform boys in ICT literacy. However, Gnambs (2021) found only small differences in ICT literacy between boys and girls at age 15. In a more recent review, Peng and Yu (2022) suggested there is no consistent evidence linking gender to digital literacy, whereas the relationship between socio-economic status and digital literacy appears to be more robust.

With respect to the specific International Computer and Information Literacy (CIL) test used in the present study, results from ICILS 2013, 2018, and more recently from the 2023 cycle, generally show a female advantage over males in computer and information literacy assessments (e.g. Punter et al., 2017; Fang et al., 2025). Additionally, gender-related beliefs have been shown to influence attitudes toward ICT use (Liong et al., 2023), underscoring the importance of considering both SES and gender together toter understand their impact on ICT use, digital literacy, and mathematical achievement.

In mathematics achievement specifically, recent studies indicate that the use of ICT can narrow achievement gaps between genders: both male and female students benefit similarly from ICT-based mathematics instruction, and no statistically significant gender difference was observed in mathematics achievement when ICT was integrated into teaching (Salami & Spangenberg, 2024). The results of the study revealed that ICT facilities improved students' achievement and reduced the gender gap in mathematics achievement among secondary school students.

The present study: hypotheses and predictions

The literature reviewed above highlights the ongoing debate surrounding the relationship between ICT and mathematics achievement in education.

The present study aims to clarify this relationship by considering the everyday purposes of ICT use, standardized measures of digital literacy, mathematics knowledge in eighth grade compared to fifth grade, while controlling for gender and sociocultural factors. Fifth grade was chosen as the baseline for comparison because, in the Italian education system, specific computer skills or ICT familiarity competencies are formally introduced as learning objectives only at the beginning of grade six (Italian Ministry of Education, University and Research, 2012). To our knowledge, no systematic study has yet examined the association between digital literacy, as assessed by the standardized CIL test, and mathematical achievement.

Consistently with previous research, we hypothesize that mathematics performance in fifth grade strongly predicts performance in eighth grade, even when controlling for gender and socioeconomic status (SES).

Additionally, we expect that digital literacy, measured through standardized assessments, and self-reported ICT use for educational purposes are positively correlated with improvement in mathematics learning outcomes from fifth to eighth grade. In contrast, we anticipate a negative relationship between ICT use for social purposes and mathematics achievement.

Finally, the study explores whether digital literacy helps mitigate mathematics achievement disparities related to gender and socioeconomic status. Despite ongoing discussions about these disparities, little research has focused on the potential role of digital literacy in reducing achievement gaps in mathematics, making this a crucial area of investigation. By

addressing these questions, the study aims to contribute to a deeper understanding of how ICT use and digital literacy are related to mathematics learning outcomes.

Methods

Participants

A representative sample of 2810 Italian students, grouped in 150 schools across all Italian regions was recruited to participate in the ICILS 2018, the IEA international comparative study of Computer and Information Literacy at the eighth grade. The same students also participated in the national mathematics assessment carried out by INVALSI (National Institute for the Evaluation of the Education and Training System). Participants completed the INVALSI math test in both fifth grade (2016) and eighth grade (2019).

After excluding students who did not complete all three surveys, the final sample consisted of 2309 students (51% boys) clustered in 150 schools. The mean age of participants was 10.8 (SD = 0.44) in fifth grade and 13.7 (SD = 0.34) in eighth grade.

Measures

Gender and socio-economic and cultural status (*SES*) were among the variables collected through the ICILS student questionnaire.

For SES, the questionnaire included questions that required students to provide open-ended responses about their parents' occupational status. The responses were then classified according to the International Standard Classification of Occupations (ISCO-08) framework (International Labour Organization, 2012). Additionally, students provided information on their parents' educational attainment and reported on the availability of home literacy resources, specifically the number of books in their households. An SES index was computed by aggregating scores from these three dimensions: parental occupation, parental education, and number of books at home. This index was standardized at the national level with a mean of 0 and a standard deviation of 1.

ICT use: Self-reported ICT use was assessed through the Student Questionnaire of the ICILS 2018 survey. Participants rated their frequency of ICT usage on a 5-point frequency scale, ranging from "Never" to "Every day." The questionnaire included 11 items that measured their frequencies of ICT use for various purposes. Exploratory Structural Equation Modeling (ESEM) that combines the strengths of exploratory and confirmatory factor analyses (Asparouhov & Muthén, 2009; Marsh et al., 2009, 2014) was performed and evidenced a clear two-factor solution (CFI = 0.96; TLI = 0.94; SRMR = 0.03; RMSEA = 0.05). The detailed ESEM results are reported in Appendix.

The first factor (accounting for 52% of the explained variance) comprised items related to ICT use for study purposes, such as "Prepare reports or essays" and "Use software or applications to learn skills or a subject", with factor loadings ranging from 0.45 to 0.79. The second factor (accounting for 40% of explained variance) included items related to ICT use for social communication, such as "Post images or videos on social networks or online communities" and "Write posts and updates about what happens in your life on social media," with factor loadings ranging from 0.38 to 0.55. The correlation between the factors is small (0.10).

Based on the ESEM results, the items were summed to obtain two independent measures: Use of ICT for Study (6 items; Cronbach's alpha = 0.70) and Use of ICT for Social Communication (5 items; Cronbach's alpha = 0.75). Higher scores indicate more frequent use of ICT for study or social communication, respectively.

Computer and Information Literacy Scale (CIL): ICT literacy was assessed using the IEA CIL test, which consists of a series of tasks set in real-world contexts. CIL is divided into four strands: understanding computer use, gathering information, producing information, and digital communication. Using Item Response Theory (IRT), five plausible values were generated for each student as estimates of their ICT Literacy. These values estimate the unobserved latent ability of an individual, and they reflect the magnitude of measurement error by providing a range of five possible scores for each student (see Wu, 2005). In the present study, the CIL scores were calculated from these five plausible values, and they were standardized on a scale with a mean of 500 and a standard deviation of 100 (for a detailed description, see Fraillon et al., 2020). The CIL results are categorized in three proficiency levels based on established cutoffs. The low level includes students with undeveloped or basic skills (up to 491 points on the CIL scale); the intermediate level includes students who score between 492 and 576 on the CIL scale and who are able to perform computer tasks following direct instructions; the higher level includes students scoring above 576 points on the CIL scale and demonstrating the ability to perform tasks accurately, autonomously, and critically (for a detailed description of the levels see Fraillon et al., 2020).

INVALSI Mathematics Achievement Scales: The mathematics scale consists of closed and open-ended questions from the Italian Annual Survey on Educational Achievement conducted by INVALSI, which is a census-based assessment. This scale measures three cognitive domains—Solving Problems, Arguing, and Knowing, across four content domains: Numbers, Space and Figures, Data and Predictions, and Relations and Functions (for a detailed description, see INVALSI, 2018). The items were evaluated through qualitative evaluation by experts and iterative psychometric analyses based on the Rasch model of measurement. They were calibrated onto the same metric of the INVALSI mathematics item bank for the National Assessment program (for details, see Desimoni, 2018). For grade 5, a single booklet, the same for all students, is administered, thus producing a complete data matrix and reducing measurement error. For each grade, IRT estimates were standardized, with a mean value of 200 and a standard deviation of 40 (for a detailed description, see INVALSI, 2019).

Data analysis

Descriptive statistics and correlational analyses were first conducted using IBM SPSS Statistics (version 27). Gender differences were tested using independent samples *t*-tests. For CIL scores, a *t*-test was performed using multiple imputations to account for the five plausible values, utilizing the IEA International Database (IDB) Analyzer software, version 5.0 (IEA, 2024). The cases were weighted to ensure representativeness of the population of Italian students.

Since the Italian grade 5 mathematics achievement variable could have been included as a background variable (see Wu, 2005), new plausible values were computed. The correlation between these new plausible values incorporating this variable and the original ones was, on average, 0.94. Considering the high correlation, for the purposes of this study, the original plausible values were retained to ensure comparability with international results.

To examine how mathematics achievement at fifth grade and ICT-related variables are associated with mathematics achievement at eighth grade, a structural equation modeling (SEM) approach was adopted by means of Mplus 8.2 (Muthén & Muthén, 2019).

Fifth-grade mathematics achievement, observed CIL scores, and latent constructs of "ICT use for study" and "ICT use for social communication" were included as predictors of eighth-grade mathematics achievement. The latent variables were constructed using the parceling method based on item-total correlations (Little et al., 2002). To account for the potential confounding role of SES, this variable was included in the model as an independent predictor.

Statistical moderation analysis was conducted to test the role of gender in the relationship between predictors and the outcome variable, eighth-grade mathematics performance. A Wald Test was performed to explore whether gender moderates the relationship. If the Wald test shows that the parameters for gender are not significantly different from zero, the gender variable is removed from the model. A significant difference—β^ is significantly different from β0 (null hypothesis, β0 = 0)-—suggests that the inclusion of gender (the estimate of β) improves model fit, indicating its significance.

To evaluate the predictive value of the model, R-squared values were computed. Model fit was assessed using different indices: the Comparative Fit Index (CFI) and TLI (Tucker-Lewis Index), where values at least equal to 0.95 indicate a good model fit (Bentler, 1990; Hu & Bentler, 1999); the Root Mean Square Error of Approximation (RMSEA) where values lower than 0.05 suggest a good fit (Browne & Cudeck, 1992); and the Standardized Root Mean Square Residual (SRMR) where values less to 0.08 indicate a good fit (Hu & Bentler, 1999).

Results

Table 1 shows the descriptive statistics for the total sample as well as separately for females and males. The right side of the table reports correlation coefficients among the study variables.

Digital literacy (CIL scores) was strongly positively correlated with math performance in both the fifth and eighth grades. However, the frequency of ICT use for study or for social communication was not significantly associated with either digital literacy or mathematics achievement at either grade.

Regarding gender differences, boys outperformed girls in mathematics performance in both the fifth and eighth grades, while girls outperformed boys in digital literacy (i.e., CIL scores). Girls used technology for social communication purposes more frequently than boys (15.99 vs 14.50). Gender differences in ICT use for study purposes were also significant; however, the effect size was minimal (13.90 for females vs. 13.93 for males, Cohen's $d = 0.10$).

With respect to socio-economic and cultural status, SES was positively associated with mathematics achievement in the fifth grade, and this relationship strengthened in the eighth-grade. SES was highly positively correlated with CIL scores, while its relationships with self-reported use of ICT was negligible.

A structural equation model was performed to test the relationship between study variables and assess the role of ICT-related variables in changes in math performance from fifth to eighth grade.

Table 1 Descriptive statistics and correlations

Means (S.E.) for the total sample and males and females				Correlations (S.E.) between study variables					
	Total (N=)	Females (N=)	Males (N=)	Math_5th-grade	Math_8th-grade	CIL TEST performance	ICT use for study	ICT use for social communications	SES
MATH PERFORMANCE									
Math_5th-grade	200.00 (0.05)	197.12 (0.08)	202.50 (0.08)	-	**0.48** (0.03)	**0.28** (0.03)	−0.03 (0.02)	−0.08 (0.02)	0.19 (0.03)
Math_8th-grade	200.00 (0.05)	198.01 (0.08)	201.91 (0.09)		-	**0.52** (0.03)	−0.08 (0.03)	−0.09 (0.03)	**0.33** (0.02)
ICT LITERACY AND ICT USE									
CIL TEST performance	**466,66 (2.84)**	**474,12 (3.73)**	**459.34 (3.33)**			-	−0.08 (0.03)	0.05 (0.03)	**0.31** (0.02)
ICT use for study	13.91 (0.01)	13.90 (0.01)	13.93 (0.01)				-	**0.29** (0.03)	0.04 (0.02)
ICT use for social communications	**15.23 (0.01)**	**15.99 (0.01)**	**14.50 (0.01)**					-	−0.01(0.03)

Note. All correlation are statistically significant at $p<0.01$

Statistically significant gender differences and correlation coefficients greater than.20 are reported in boldface.

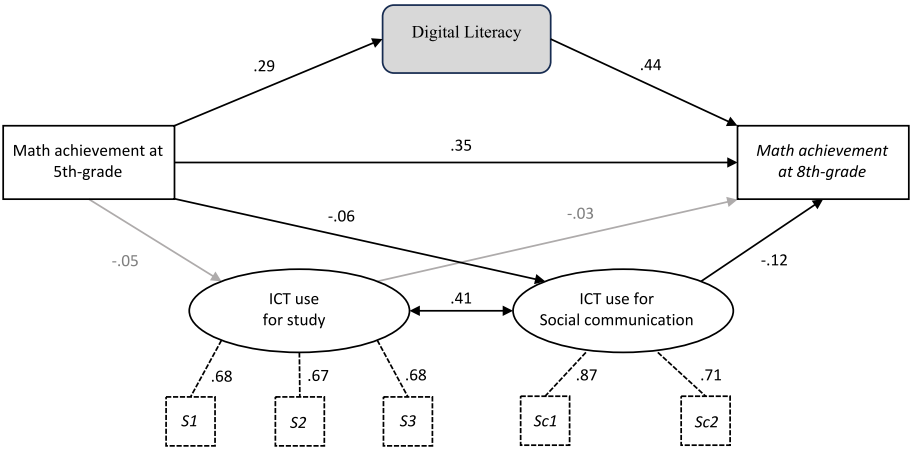

Fig. 1 Relationships between CIL, ICT use and mathematics achievement: direct effects. $R^2 = 0.43$; Rmsea = 0.02; CFI = 0.99; TLI = 0.99; SRMR = 0.02. To improve the readability of Fig. 1, the measurement errors and the association between SES and study variables are not reported

The structural equation model showed good fit indices (RMSEA = 0.02, CFI = 0.99, TLI = 0.99; SRMR = 0.02), explaining 43% of the variance in eighth-grade mathematics achievement, ranging from 42% for females to 44% for males. The moderation analysis did not reveal a significant gender difference (Wald Test = 0.02, n.s.), indicating that the relationship between study variables did not vary between males and females.

Mathematics achievement in eighth grade was strongly and positively associated with CIL (β =.44, $p < 0.01$) and previous mathematics achievement in the fifth grade (β =.35, $p < 0.01$). ICT use for social purposes was negatively associated with mathematics achievement ($\beta = -0.12$, $p < 0.01$). Specifically, greater use of ICT for social purposes was associated with lower performance on the INVALSI mathematics test (see Fig. 1). In contrast, ICT use for study purposes and SES were not correlated with eighth-grade mathematics achievement. The relationship between SES and mathematics achievement was found to be significant and positive only for fifth-grade mathematics achievement (β =.02, $p < 0.01$).

Figure 1 illustrates the pattern of relationships between CIL, ICT use for social purposes, ICT use for study purposes, and mathematics achievement.

For illustrative purposes, Fig. 2 displays the differences in mathematics performance between the fifth and eighth grades for students with low, medium, and high ICT literacy. The figure clearly shows that mathematics performance decreased from the fifth to the eighth grade for students in the low ICT literacy group, while it increased for students in the high ICT literacy group.

Discussion

An ongoing debate, characterized by highly polarized and conflicting positions, has emerged in recent decades regarding the influence of new technologies on students' cognitive processes and abilities across various disciplines. Some argue that the pervasive daily use of electronic devices leads to the deterioration of basic cognitive skills, while others highlight the potential benefits that technology can offer to learning, particularly at younger

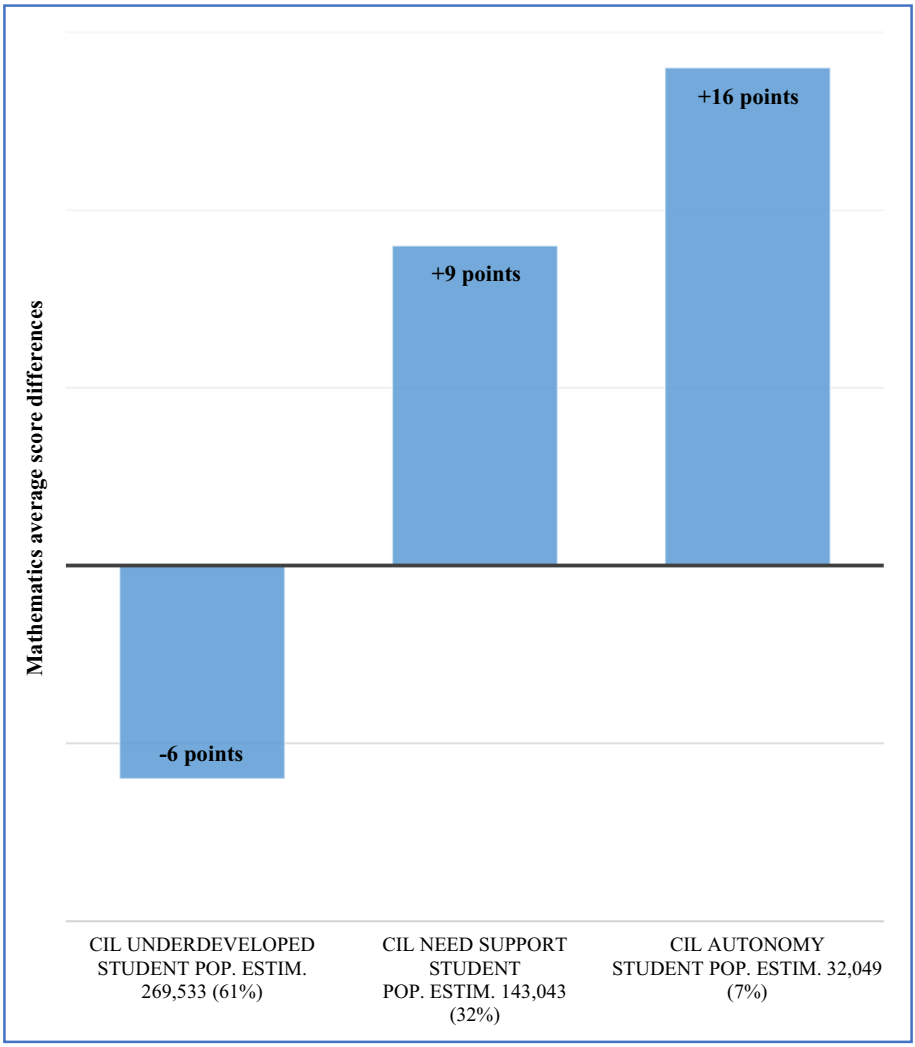

Fig. 2 Mathematics average score differences across years from 2016 (5th grade) to 2019 (8th grade)

ages (e.g., Shanmugasundaram & Tamilarasu, 2023; Straker et al., 2009). Mathematical performance, in particular, has been repeatedly linked to the use of new technologies, with mixed findings. It should be noted that prior studies have relied on self-reported measures of ICT usage, without investigating the association with ICT literacy, i.e., how effectively students use new technologies. In sharp contrast, the present study clearly indicates that ICT literacy, as objectively measured, is a key concept that should be considered in understanding the complex relationships between technology use and changes in mathematics performance.

In line with the existing literature (Bailey et al., 2014; Schadl & Ufer, 2023; Siegler et al., 2012), early competence in mathematics is strongly related to future achievement in the subject, while difficulties in the early years can lead to persistent underachievement in mathematics.

Our model, which successfully explained 43% of the variance in eighth-grade mathematics performance, demonstrates that students with strong digital literacy skills show greater improvements in mathematics over time. To the best of our knowledge, this is the first study to highlight the role of ICT literacy in mediating changes in mathematics performance between the fifth and eighth grades in a large, nationally representative sample of Italian students. This finding underscores the importance of measuring ICT literacy, rather than simply the frequency of technology use, in understanding its relation to mathematics achievement.

The strong relationship between digital literacy and mathematics achievement observed in the present study can be explained by the fact that the use of educational applications, such as Wikis (Biasutti & EL-Deghaidy, 2014) and blogs (Ebner et al., 2010), can improve learning outcomes, motivate students, and improve school performance. For instance, software applications like databases and Excel spreadsheets foster inquiry-based learning, while multimedia tools support cognitive processes by aiding learners' thinking activities and facilitating the sharing and expression of their knowledge (Biasutti & EL-Deghaidy, 2014). These tools help students actively engage with mathematical concepts, enabling them to develop problem-solving and independent learning strategies, which are crucial for mathematics achievement. In this line, an informed and competent use of ICT can be a valuable resource for students, developing higher-order critical thinking and promoting deeper learning (Anastasopoulou et al., 2024; Kilag et al., 2023). This explains the result that digital literacy, rather than simple frequency of ICT use, is a significant factor of mathematical achievement in our longitudinal analysis.

Our results also highlight the limitations of an approach that merely correlates the frequency of technology use with mathematics performance. Our findings suggest that the type of activity matters more than mere usage. Contrary to what might have been expected based on Meggiolaro's study (2018), no positive relationship was found between the ICT use for study purposes and mathematics performance. More notably, ICT use for social communication was negatively associated with mathematics performance in eighth grade. This result can be explained considering the cognitive and time displacement effects of social media usage (Cheng et al., 2024), aligning with emerging research that links excessive social media usage to declines in academic performance, particularly in mathematics (Posso, 2016).

Gender and SES differences were also observed. Consistent with previous studies (e.g., Gustafsson et al., 2018; INVALSI, 2019; Li et al., 2021; von Davier et al., 2024), boys outperformed girls in mathematics in both the fifth and eighth grades. This finding contributes to the extensive and well-documented gender gap in STEM fields, with females consistently underperforming relative to their male counterparts. Furthermore, it underscores efforts to identify strategies to reduce this gap by addressing its underlying determinants. In this context, it is essential to note that the relationship between ICT literacy and mathematics achievement does not differ by gender, indicating that ICT literacy may be equally relevant to supporting mathematics performance among both male and female students. Additionally, we found that girls used technology for social communication purposes more frequently than boys, which is consistent with prior studies that show females often use ICT for more social and communicative purposes, such as interacting in chat rooms, reflecting a more practical and socially oriented approach (e.g., Caponera et al., 2022; Leonhardt & Overå, 2021; Mumtaz, 2001). Moreover, with respect to the inconsistent previous finding (Gnambs, 2021; Peng & Yu, 2022), we found females outperform males in digital literacy (Fraillon, 2019b; Siddiq & Scherer, 2019), suggesting that ICT literacy can

serve as a compensatory factor, potentially helping to mitigate some of the disadvantages girls face in mathematics performance.

With respect to socioeconomic status, our results confirm the role of this factor in influencing mathematics performance. In line with previous findings (Selvitopu & Kaya, 2023; Sirin, 2005), we found that SES was strongly correlated with math achievement, particularly in the fifth grade, and this association grew stronger by the eighth grade, indicating that context factors reflecting the availability or unavailability of socioeconomic and cultural resources within the family have an impact on students' performance (Gustafsson et al., 2018; Li et al., 2021). Once prior achievement was controlled, SES no longer predicted CIL and eighth-grade performance, indicating that early math success mediates socioeconomic effects in later schooling, a result that aligns with the previous literature (Armor et al., 2018; Marks, 2015; Van Ewijk & Sleegers, 2010). The results further highlight that while SES factors remain crucial, early academic success plays a key role in predicting later mathematics achievements.

Our findings carry significant practical implications. They highlight that merely providing children access to devices does not automatically enhance their school performance or digital skills. Access to devices alone does not confer an advantage; rather, students' proficiency in using ICT is crucial. The study suggests that educational policymakers should focus on developing comprehensive strategies to promote responsible and effective use of educational technologies among students, integrating digital literacy in the curriculum, designing strategies to ensure that teachers and students develop ICT skills, and implementing pedagogical methods that leverage these skills in the teaching and learning of traditional subjects.

Despite the findings' clarity and robustness, this study has limitations. First, the correlational nature of the research precludes the ability to draw definitive conclusions about causal relationships between the examined variables. Second, individual differences in cognitive abilities, which could provide a deeper understanding of the association between proficient ICT use and mathematics performance, were not analyzed. Furthermore, the study was conducted in a single country, limiting the generalizability of the results to an international context, where the use of ICT in school-age children may vary significantly due to unexamined social and cultural differences. From a methodological perspective, the CIL measure does not take into account an additional conditioning variable, i.e., mathematics achievement at grade 5, to reduce measurement error.

On the other hand, the study presents different strengths. It is the first longitudinal study based on a large, representative sample of Italian children, utilizing both objective measures of digital literacy and self-reported measures of technology use for study and social purposes. Furthermore, mathematics performance was assessed using a nationally standardized test, administered across all Italian schools and designed according to the national curriculum. This ensures that the test accurately reflects the curricular mathematical knowledge and skills required of students in the fifth and eighth grades in Italy.

The first cycle of ICILS 2013 demonstrated the fallacy of assuming that young people, simply because they have grown up surrounded by digital technology, possess advanced ICT skills. "Digital natives" are not necessarily digital experts. Growing up with digital devices does not automatically translate to sophisticated digital skills, and self-reported high-frequency use of ICT does not correlate with high digital literacy scores (Fraillon et al., 2019b). In this line, the concept of "digital divide" should extend from physical access to technology to actual digital skills (Gorski, 2005; Hargittai, 2002; Vassilakopoulou & Hustad, 2023) and on the ability to apply these skills in a favorable offline outcome (Van Deursen & Helsper, 2015). The skills and resources that

enable effective use of digital technologies, including ICT knowledge, content creation, and problem-solving abilities, are often referred to as "digital capital." Beyond mere access, how students use these tools significantly impacts outcomes such as academic performance (Pitzalis & Porcu, 2024; Ragnedda, 2018).

In other words, digital literacy should be considered a central concept and a critical tool for inclusion and development (DiMaggio et al., 2004; Hsieh et al., 2011; Liff et al., 2004).

Information and Communication Technologies have revolutionized our personal and professional spheres. Schools bear a pivotal responsibility in developing ICT competencies among students to mitigate the disparities in the socioeconomic and cultural resources that exist across families. Promoting an informed and competent use of ICT in schools and fostering digital skills are fundamental imperatives to achieve better performance in mathematics.

This study shows that digital literacy, rather than the frequency of ICT use, is a key driver of mathematics achievement between the fifth and eighth grades. Students with stronger ICT skills are better positioned to use digital tools effectively for learning, which may explain their higher mathematics outcomes. By contrast, frequent use of ICT for social communication appears detrimental, likely due to its displacement of academic activities and its association with distraction.

The findings suggest that simply increasing ICT access or frequency of use will not close achievement gaps. Instead, educational policies should focus on structured digital literacy training and pedagogical strategies that enable students to apply ICT meaningfully in mathematics. Because the effect of digital literacy was consistent across genders, enhancing ICT skills may also help reduce the gender gap in mathematics. Similarly, strengthening early mathematics foundations appears crucial to mitigating the long-term effects of socioeconomic disparities.

In sum, our results indicate that how students use technology and how skilled they are in doing so matters far more than mere exposure. Developing digital literacy is therefore not only an ICT goal but a fundamental strategy for improving mathematics learning outcomes.

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Paolo Maria Russo: conceptualization, formal analysis, methodology, writing—original draft, writing—review and editing.
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Elisa Caponera.

Current themes of research:

Parental involvement at school, gender difference in achievement, student characteristics.

Most relevant publications in the field of Psychology of Education:

Damiani, V., Caponera, E., Losito, B., Palmerio, L., & Agrusti, G. (2024). Young people's civic engagement in Italy: evidence on grade 8 students from the international civic and citizenship education study (ICCS) 2016. *Large-scale Assessments in Education*, *12*(1), 36.

Caponera, E. & Palmerio, L. (2021). Do parents count for their children's mathematics achievement?. *Cadmo: giornale italiano di pedagogia sperimentale*, *1, 2021*, 99-119.

Valentina Colonnello.

Current themes of research:

Social network; learning; education.

Most relevant publications in the field of Psychology of Education:

Colonnello, V., Mattarozzi, K., Agostini, A., & Russo, P. M. (2020). Emotionally salient patient information enhances the educational value of surgical videos. *Advances in Health Sciences Education*, 25, 799-808.

Colonnello, V., Mattarozzi, K., & Russo, P. M. (2019). Emotion recognition in medical students: effects of facial appearance and care schema activation. *Medical Education*, 53(2), 195-205.

Francesco Annunziata.

Current themes of research:

Sense of belonging, student resilience, well-being at school.

Most relevant publications in the field of Psychology of Education:

Annunziata F., Caponera E., Palmerio L., (2024).*Sense of belonging at school and students with special educational needs: evidence from TIMSS 2019,* in P. Falzetti (a cura di) «Surveys on students: the INVALSI national and international tests», FrancoAngeli, Milano. *ISBN: 9788835164302, pag. 86-104.*

Caponera E., Annunziata F., Palmerio L., (2022). Computer and Information Literacy at the eighth grade: differences between boys and girls. *Culture e Studi del Sociale - CuSSoc*, Vol. 7.1, ISSN: 2531-3975, pag. 31-46.

Laura Palmerio.

Current themes of research:

Equity in education, reading literacy, civic and citizenship education.

Most relevant publications in the field of Psychology of Education:

Ajello, A. M., Caponera, E., & Palmerio, L. (2018). Italian students' results in the PISA mathematics test: Does reading competence matter?. European Journal of Psychology of Education, 33(3), 505-520.

Tramontano, C., Nocentini, A., Palmerio, L., Losito, B., & Menesini, E. (2020). Mapping community, social, and economic risks to investigate the association with school violence and bullying in Italy. *Child Abuse & Neglect, 109, 104746.*

Paolo Maria Russo.

Current themes of research:

*P*ersonality,self-reported measures, methodology.

Most relevant publications in the field of Psychology of Education:

Colonnello, V., Leonardi, G., Farinelli, M., & Russo, P. M. (2023). The relationship of psychological health and primary emotional traits in medical students. *Medical Teacher*, 45(7), 717-723.

Caponera, E., Sestito, P., & Russo, P. M. (2016). The influence of reading literacy on mathematics and science achievement. *The Journal of Educational Research*, *109*(2), 197-204.

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