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The Impact of ICT Self-Efficacy and Subject-Oriented ICT Use During Lessons on Mathematics Achievement: A PISA 2022 Türkiye Sample

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ABSTRACT

This study aims to investigate the impact of students' Information and Communication Technology (ICT) self-efficacy (ICTEFFIC) and subject-related ICT use during lessons (ICTSUBJ) on mathematics achievement. Framed within Self-Determination Theory and ICT Engagement Theory, this quantitative secondary data analysis is based on a sample of 6,599 15-year-old students (3,286 males, 3,313 females) from the Program for International Student Assessment (PISA) 2022 Türkiye cohort. Data were analyzed using multiple regression analysis based on 10 pooled plausible values in accordance with Rubin's rules, while controlling for socioeconomic status (ESCS) and gender, and employing robust standard errors to account for heteroscedasticity. The findings revealed that even when ESCS and gender were held constant, both ICT self-efficacy and subject-related ICT use significantly and positively predicted mathematics achievement. The regression model explained 15.6% of the variance in mathematics performance. Comparative results demonstrated that pedagogical, subject-related ICT use (B= 12.109, β = 0.146) had approximately twice the predictive power on mathematics achievement compared to digital self-efficacy (B= 6.284, β = 0.080). Furthermore, socioeconomic status was confirmed as the strongest predictor in the model. Regarding gender, although male students scored statistically higher on ICT variables, the effect sizes (Cohen's d) indicating practical significance remained at a negligible level. In conclusion, this study demonstrates that students' mere psychological competence (self-efficacy) is not solely sufficient for digital technologies to positively contribute to academic achievement. For academic benefit, it is imperative that this digital belief translates into action through curriculum-integrated, teacher-guided, and pedagogically purposeful use in the classroom environment.

BİT Öz Yeterliğinin ve Derslerde Konu Odaklı BİT Kullanımının Matematik Başarısına Etkisi: PISA 2022 Türkiye Örneklemi

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ÖZET

Bu çalışma, öğrencilerin Bilgi ve İletişim Teknolojileri (BİT) öz yeterliklerinin (ICTEFFIC) ve ders sırasında konuyla ilgili bilgi ve iletişim teknolojileri kullanımlarının (ICTSUBJ) matematik başarısı üzerindeki etkisini incelemeyi amaçlamaktadır. Öz Belirleme Kuramı ve Dijital Katılım Kuramı çerçevesinde şekillendirilen bu nicel ikincil veri analizi, Uluslararası Öğrenci Değerlendirme Programı (PISA) 2022 Türkiye örnekleminden 15 yaşındaki 6.599 öğrenciye (3.286 erkek, 3.313 kız) dayanmaktadır. Veriler; sosyoekonomik düzey (ESCS) ve cinsiyet kontrol altına alınarak ve değişen varyans (heteroskedastisite) durumunu hesaba katmak amacıyla dirençli standart hatalar (robust standard errors) kullanılarak, Rubin'in kuralları doğrultusunda birleştirilmiş 10 olası değer (plausible values) üzerinden çoklu regresyon analizi ile incelenmiştir. Bulgular, ESCS ve cinsiyet sabit tutulduğunda dahi, hem BİT öz yeterliğinin hem de konuyla ilgili BİT kullanımının matematik başarısını anlamlı ve pozitif yönde yordadığını ortaya koymuştur. Regresyon modeli, matematik performansındaki varyansın %15,6'sını açıklamıştır. Karşılaştırmalı sonuçlar, pedagojik olarak konuyla ilgili BİT kullanımının (B = 12.109, β = 0.146) matematik başarısı üzerinde, dijital öz yeterliğe (B = 6.284, β = 0.080) kıyasla yaklaşık iki kat daha fazla yordayıcı güce sahip olduğunu göstermiştir. Ayrıca, sosyoekonomik düzeyin modeldeki en güçlü yordayıcı olduğu doğrulanmıştır. Cinsiyet açısından, erkek öğrenciler BİT değişkenlerinde istatistiksel olarak daha yüksek puanlar almış olsalar da pratik anlamlılığı gösteren etki büyüklüklerinin (Cohen's d) ihmal edilebilir düzeyde kaldığı görülmüştür. Sonuç olarak bu çalışma, dijital teknolojilerin akademik başarıya olumlu katkı sağlaması için öğrencilerin salt psikolojik yeterliklerinin (öz yeterlik) tek başına yeterli olmadığını göstermektedir. Akademik fayda sağlanabilmesi için, bu dijital inancın sınıf ortamında müfredata entegre edilmiş, öğretmen rehberliğinde ve pedagojik olarak amaca uygun bir kullanımla eyleme dönüşmesi elzemdir

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INTRODUCTION

The integration of information and communication technologies (ICT) into education systems is accelerating globally in the 21st century, and the effects of this process on students' academic achievement are attracting increasing attention (Caponera, Colonnello, Annunziata, Palmerio & Russo, 2026). PISA 2022 findings and related research indicate that moderate digital device use in the school environment is associated with higher academic performance; however, the relationship between high-level use and achievement is not simple and linear, but rather can create an inverted U-shaped contrast by causing cognitive overload (Sweller, 1988) after a certain threshold (Li & Zhu, 2023; Örnek & Afari, 2026). This finding highlights that simply having access to or intensive use of devices does not automatically improve educational outcomes; rather, the quality of use, pedagogical context, and the quality of technology use—also referred to as "digital capital"—are decisive factors (Petko, Cantieni & Prasse, 2017; Caponera et al., 2026).

Türkiye stands out as a country where only 61% of its students achieved Level 2 or higher in the PISA 2022 mathematics assessment, significantly below the OECD average (69%) (OECD, 2023). Especially in the recent past, Türkiye, having implemented large-scale digital infrastructure investments such as the FATIH (Enhancing Opportunities and Improving Technology) Project and accelerating ICT policies (Ünal, Uzun & Kilis, 2022; Örnek & Afari, 2026), offers a unique and policy-valued context for examining the relationship between ICT and mathematics achievement. However, empirical evidence on the extent to which these enormous public investments have translated into students' academic success is still limited, and the need for current, systematic, and quantitative analyses in the Turkish context is further highlighted by the new generation of PISA data (Erdoğdu & Erdoğdu, 2015).

Literature addressing the relationship between ICT use and academic achievement on a global scale largely reports inconsistent findings (Areepattamannil & Santos, 2019; Odell, Cutumisu & Gierl, 2020). While some studies argue that ICT use improves achievement (Wei & Zhang, 2025), others have shown mixed or meaningless relationships (Bulut & Cutumisu, 2020; Courtney, Karakuş, Ersözlü & Nurumov, 2022); and still others have consistently shown that—particularly general-purpose use at school or excessive entertainment use at home—negatively impacts mathematics and science achievement (Unal et al., 2022; Zhang & Liu, 2016). The main reason for this inconsistency in findings is that ICT use is modeled as a one-dimensional and linear "exposure" process, ignoring how and for what purpose students use technology (Örnek & Afari, 2026). Indeed, recent studies have shown that intensive ICT use alone does not predict success; however, structured use that is appropriate to its purpose (academic and course-focused) increases success, while uncontrolled use focused on leisure time, social interaction, or gaming decreases success (Hu, Gong & Lai, 2018; Wei & Zhang, 2025; Caponera et al., 2026).

This study, drawing on Self-Determination Theory (SDT) and Digital Engagement (ICT Engagement) (Zylka, Christoph, Kroehne, Hartig & Goldhammer, 2015; Kunina Habenicht & Goldhammer, 2020), aims to examine the predictive power of ICT self-efficacy (ICTEFFIC) and subject-related ICT use (ICTSUBJ) variables on the PISA 2022 mathematics achievement of 15-year-old students in Türkiye. In the analyses, confounding factors such as socioeconomic status (ESCS) and gender, known to have strong and stable effects on academic achievement, will be controlled; as research shows that advantaged socioeconomic groups and male students exhibit significant structural differences in their patterns of access to and use of technology (Biagi & Loi, 2013; Hristov, Yada, Fagerlund, Näykki & Häkkinen, 2026). The scarcity of studies in the existing literature that utilize the PISA 2022 Türkiye dataset to simultaneously test the psychological dimensions of technology (i.e., self-efficacy and purpose of use)—rather than its mere quantity—through a parsimonious and reproducible regression model constitutes the originality and scholarly contribution of this research. To achieve this overarching purpose, the study specifically addresses the following research questions:

RQ1: How are the levels of ICT self-efficacy and subject-related ICT use distributed among 15-year-old students in Türkiye?

RQ2: Do ICT self-efficacy and subject-related ICT use exhibit significant differences based on gender?

RQ3: Do ICT self-efficacy and subject-related ICT use significantly predict mathematics achievement when socioeconomic status (ESCS) and gender are controlled?

Theoretical Framework Research Design

Self-Determination Theory

Self-Determination Theory (SDT; Deci & Ryan, 1985; Ryan & Deci, 2017) is a comprehensive and empirically based psychological framework developed to explain individuals' intrinsic motivation and self-regulation capacity. According to SDT, optimal human functionality, the development of treatment methods, and well-being depend on the fulfillment of three fundamental universal psychological needs: competence, autonomy, and relatedness (Ryan and Deci, 2000). Competence refers to an individual's belief in their ability to effectively cope with their environment, develop their abilities, and achieve desired outcomes; autonomy reflects the need for individuals to direct and act according to their own will and values without any external pressure (Ryan and Deci, 2017). Relatedness encompasses the components of establishing meaningful connections, feeling a sense of belonging to a group, and bonding with others (Ryan and Deci, 2000). In environments where these three needs are met, individuals' intrinsic motivation increases, and they successfully internalize externally motivated tasks (e.g., compulsory school assignments), incorporating them into their self-regulation processes. Conversely, in controlling environments where needs are thwarted or suppressed, intrinsic motivation weakens, alienation occurs, and academic performance and sustained effort are negatively affected (Ryan and Deci, 2000; Ryan and Deci, 2017).

Self-Determination Theory (SDT) has been widely used in research on academic achievement; consistent positive relationships have been found between students' intrinsic motivation for learning, self-regulation skills, and perceived competence, and their academic success (Ryan & Deci, 2017; Areepattamannil & Santos, 2019). In this context, students' feeling of competence in a particular area and their ability to manage that area with their own autonomous decisions stands out as a critical psychological mechanism that shapes not only their engagement in that area but also their overall academic performance.

Digital (ICT) Engagement Theory

The Digital Engagement Theory, which emerged from the adaptation of Self-Determination Theory (SDT) to the context of information and communication technologies (ICT), goes beyond mere cognitive and hardware technology use and focuses on the motivational and metacognitive processes behind technology (Zylka, et al. 2015; Kunina-Habenicht & Goldhammer, 2020). This theory, conceptually framed by Goldhammer et al. (2017) and validated by Kunina-Habenicht and Goldhammer (2020) through international PISA data, explains students' ICT engagement through four fundamental dimensions: (1) ICT Interest: The individual's long-term, content-specific, and intrinsic motivational inclination to engage with digital tasks and activities; (2) Perceived ICT Competence/Efficacy: The individual's self-efficacy belief that they can effectively use their own ICT knowledge and skills; (3) Perceived ICT Autonomy: The individual's feeling of control that they can solve problems encountered in digital environments independently and self-directed, without external constraints; and (4) ICT as a Topic in Social Interaction: The level at which digital tools are used for social interaction, communication, and information sharing with peers (Kunina-Habenicht & Goldhammer, 2020).

According to the theory, these four dimensions directly align with the fundamental universal psychological needs of SDT as “autonomy, competence, and relatedness” and positively influence academic performance by facilitating students’ purposeful, competent, and engaged use of technology, driven by their own autonomous will rather than external compulsion (Li & Zhu, 2023). The contradictory (or negative) findings frequently reported in the literature regarding the relationship between the amount of ICT use and achievement stem from neglecting these psychological dynamics behind technology. Indeed, a structural equation modeling study conducted by Li and Zhu (2023) using PISA data from 52 countries revealed that cognitive-motivational ICT engagement acts as a significant and strong mediator between technology use and academic achievement. This finding supports the idea that ICT use does not directly and automatically increase achievement; rather, the effect is transformed into a positive learning outcome only through the student's digital autonomy and other psychological engagement processes.

This study operationalizes the perceived ICT self efficacy dimension of the Digital Engagement Theory with the ICTEFFIC (Self-Efficacy in Digital Competencies) index and the behavioral engagement dimension in the learning context with the ICTSUBJ (Subject-Related ICT Use in the Lesson) index, in line with the updated assessment framework of PISA 2022 (OECD, 2024). Unlike previous PISA cycles, the ICTEFFIC, further customized in PISA 2022, reflects the student's self-efficacy perception in both basic Computer and Information Literacy (CIL) tasks such as online information searching and text editing, and advanced Computational Thinking (CT) tasks such as computer programming and algorithmic problem solving (OECD, 2024; Hristov et al., 2026); while ICTSUBJ represents the level at which this perceived competence is translated into pedagogical action in specific lesson settings. The study does not specifically claim to mediate; instead, this study aims to test the independent predictive power of these two dimensions of digital engagement on mathematics achievement, while keeping control variables such as socioeconomic status (SES) and gender constant, using a descriptive-level analysis. Thus, the goal is to provide a empirical contribution not only to the motivational dimensions of the theory but also directly to the academic outcome (achievement) dimension.

Digital Self-Efficacy (ICTEFFIC) and Academic Achievement

Based on social cognitive theory, digital self-efficacy refers to students’ belief in their own capacity to perform specific tasks or achieve goals using digital resources (Bandura, 1997; Hatlevik, Scherer & Christophersen, 2017; Örnek & Afari, 2026). Updated and expanded as the "Digital Self-Efficacy (ICTEFFIC)" index in the PISA 2022 assessment, this construct encompasses both basic Computer and Information Literacy (CIL) tasks such as online information searching and text editing, as well as more advanced Computational Thinking (CT) skills such as computer programming and algorithmic problem solving (OECD, 2024; Hristov et al., 2026). The literature emphasizes that students’ high belief in their ability to use digital tools effectively (self-efficacy) enables them to not give up in the face of academic challenges, to better design learning strategies, and to interact productively with technology (Wang & Chu, 2023; Hristov et al., 2026).

Furthermore, empirical studies consistently show that digital self-efficacy (and perceived ICT competence as measured in previous PISA cycles) is one of the strongest factors that significantly and positively predicts achievement in mathematics, science, and reading (Hu et al., 2018; Areepattamannil & Santos, 2019; Courtney et al., 2022; Ünal et al., 2022). In the current literature, ICTEFFIC is seen as more than just a predictor of academic achievement; in the complex relationship between the unstructured or recreational use of technology and academic achievement, it stands out as a "protective" and transformative, regulatory mechanism (Li & Zhu, 2023; Örnek & Afari, 2026; Hristov et al., 2026). In other words, whether the use of ICT at school or at home provides an academic benefit to the student largely depends on the student's high self-efficacy perception in using these tools strategically and purposefully (Örnek & Afari, 2026).

Subject-Related ICT Use in Lessons (ICTSUBJ) and Academic Achievement

Studies examining the impact of educational technologies in schools emphasize not just "how much" technology is used, but "in what context and for what purpose" it is used. The "Subject-Related ICT Use in Lessons (ICTSUBJ)" index included in the PISA 2022 survey measures how frequently digital resources are integrated into learning and teaching processes in specific subject areas such as mathematics, science, and language (OECD, 2024). Research shows that the general and unstructured use of ICT in schools (e.g., simply browsing the internet or using email) often negatively impacts academic achievement by leading to cognitive overload or distraction (Hu et al., 2018; Courtney et al., 2022). However, the subject-focused and teacher-guided use of digital tools in a way that directly serves the pedagogical objectives of the lesson (ICTSUBJ) has a very different dynamic on learning outcomes (Acun- Çelik, Elgün & Kalelioğlu, 2024).

This conceptual differentiation is also supported by empirical findings based on a Turkish sample. In their research, Acun Çelik et al. (2024) revealed that while the use of general-purpose ICT in schools (USESCH) negatively predicted mathematics and science achievement, the subject-related use of ICT integrated into subjects such as mathematics and science during lessons positively contributed to student achievement. Current analyses at the international level also confirm that ICT functions as a factor that increases mathematics achievement when technology and subject-specific pedagogy are combined (Wei & Zhang, 2025). In this context, ICTSUBJ stands out as a critical variable reflecting the vital importance of the compatibility of technological tools with the curriculum and lesson content, rather than the duration of "exposure" to technology investments in the transformation of academic achievement.

METHOD

Research Design

This study is designed as a secondary data analysis study in a quantitative, correlational survey design using PISA 2022 data. Correlational survey models are research approaches that aim to determine the existence and/or degree of covariation between two or more variables (Karasar, 2020). This design allows the current situation to be presented as it is without manipulating the variables (Fraenkel, Wallen & Hyun, 2012).

Since the study utilizes data from a large-scale international achievement test, secondary data analysis was adopted as the method. Secondary data analysis is the process of re-analyzing ready-made datasets previously collected by other researchers, institutions, or organizations for specific purposes to test new hypotheses or research questions (Glass, 1976; Johnston, 2014). This approach; by leveraging the advantages offered by objective databases with large sample sizes, high sampling power, and methodological standards, such as PISA, time and cost savings are achieved while maximizing the generalizability and external validity of the findings (Smith, 2008).

Data Source and Sample

The research data was obtained from the PISA (Programme for International Student Assessment) database, conducted by the Organization for Economic Cooperation and Development (OECD) in 2022.

PISA is an international assessment program that evaluates the proficiency of 15-year-old students in mathematics, science, and reading literacy.

The analysis consists of 7,250 students from Türkiye who participated in PISA 2022. After removing missing data using the listwise deletion method, the analysis sample reached 6,599 students (Male = 3,286, Female = 3,313). The 651 missing observations (9.0%) are due to missing data in the ICTEFFIC and ICTSUBJ indices.

Measurement Tools

ICT Self-Efficacy (ICTEFFIC): A ready-made index created by the OECD using Item Response Theory (IRT) to measure students' self-efficacy perceptions regarding general digital technology use. The index is derived from IC175 items in the PISA 2022 ICT Questionnaire.

Subject-Related ICT Use in Lessons (ICTSUBJ): A ready-made index created by the OECD using IRT to reflect the frequency of students' use of digital technology in mathematics, science, and language courses. It is derived from IC173 items.

Mathematics Achievement: Measured through the PISA 2022 mathematics test. Ten PVs were generated for each student using the plausible value method, and pooling was applied in the analyses according to Rubin's (1987) rules.

Control Variables: The socioeconomic, social, and cultural status index (ESCS) and gender (0 = Male, 1 = Female) were included in the analysis as control variables. ESCS was included in the model because it is a consistently documented predictor of mathematics achievement in the literature.

Data Analysis

Analyses were performed using R 4.6.0 statistical software. Descriptive statistics, independent samples t-test, and multiple regression analysis were applied in accordance with the research questions.

Assumption Checks: Due to the large sample size ($n = 6{,}599$), a formal normality test (e.g., Shapiro-Wilk) was not applied within the framework of the Central Limit Theorem. However, skewness and kurtosis values were calculated to describe the distribution of the variables; all values were found to be within acceptable limits (skewness: -0.529 to 0.566; kurtosis: -0.499 to 0.253). Outlier analysis ($z > 3.29$ criterion) was applied, and one observation each was detected in the PVMATH and ESCS variables (0.02%); these values were not removed from the analysis sample.

Gender Comparison: The Levene equivalence of variance test yielded significant results for both ICT variables (ICTEFFIC: $F = 7.94$, $p = .005$; ICTSUBJ: $F = 28.19$, $p < .001$). Based on this finding, the Welch independent samples t-test was applied. Cohen's d effect size was calculated to assess practical significance, as statistical significance in large samples does not guarantee practical significance.

Multiple Regression: Multicollinearity between predictors was evaluated by examining VIF values (1.009 - 1.052) and correlations between variables ($r < .25$), and no problems were found. The Breusch-Pagan test showed the presence of heteroskedasticity ($BP = 100.609$, $p < .001$); therefore, HC3 robust standard errors were used in all regression models. The Durbin-Watson statistic ($DW = 1.981$, $p = .221$) confirmed the independence of the errors. The coefficients and robust standard errors obtained from the regression models, which were run separately on 10 calculated PVs (plausible values) related to mathematical performance, were pooled according to Rubin's (1987) rules. The pooled B (unstandardized) coefficients, robust standard errors, t-statistics, and p-values are reported.

FINDINGS

RQ1: Descriptive Statistics of ICT Variables

Descriptive statistics on the ICT self-efficacy (ICTEFFIC) and subject-related ICT use in lessons (ICTSUBJ) levels of students in Türkiye are presented in Table 1.

Table 1
Descriptive Statistics Regarding ICT Variables

Variable	Group	N	Mean	SD	Min.	Max
ICT Self-Efficacy (ICTEFFIC)	All	6599	0.011	1.111	-2.648	2.284
	Male	3286	0.049	1.065	-	-
	Female	3313	-0.027	1.154	-	-
Subject-Related ICT Use (ICTSUBJ)	All	6599	0.097	1.056	-2.031	1.950
	Male	3286	0.161	1.006	-	-
	Female	3313	0.034	1.099	-	-
Mathematics Achievement (PV10MATH)	All	6599	456.95	85.46	237.09	751.76

Note: ICTEFFIC and ICTSUBJ are scaled using IRT with OECD mean=0 and SD=1.

When Table 1 is examined, the mean score for students' ICT self-efficacy is found to be very close to the OECD baseline (M = 0.011, SD = 1.111), while their subject-related ICT use during lessons exhibits a slightly positive inclination above the OECD average (M = 0.097, SD = 1.056). A descriptive breakdown by gender indicates that male students possess higher average scores than female students in both ICT self-efficacy (M = 0.049, SD = 1.065 vs. M = -0.027, SD = 1.154) and subject-related ICT use (M = 0.161, SD = 1.006 vs. M = 0.034, SD = 1.099). Lastly, the mean mathematics achievement score of the Turkish cohort is calculated as 456.95 points (SD = 85.46), spanning across a wide distribution between a minimum score of 237.09 and a maximum score of 751.76.

RQ2: Comparison of ICT Variables by Gender

To determine whether ICT self-efficacy and the level of subject-related ICT use differed according to gender, the Welch independent samples t-test and Cohen's d effect size were calculated. The findings are presented in Table 2.

Table 2
Comparison of ICT Variables by Gender

Variable	Male Mean (SD)	Female Mean (SD)	t	sd	p	Cohen's d
ICT Self-Efficacy (ICTEFFIC)	0.049 (1.065)	-0.027 (1.154)	2.800	6562.6	.005	0.069
Subject-Related ICT Use (ICTSUBJ)	0.161 (1.006)	0.034 (1.099)	4.902	6555.3	< .001	0.121

Note. Welch's independent samples t-test was used due to the violation of homogeneity of variance (Levene's p < .05).

As illustrated in Table 2, male students scored statistically significantly higher than female students in both ICT self-efficacy (Male M = 0.049, Female M = -0.027; t(6562.6) = 2.800, $p = .005$) and subject-related ICT use (Male M = 0.161, Female M = 0.034; t(6555.3) = 4.902, $p < .001$). However, the effect sizes calculated for both variables (ICTEFFIC: d = 0.069; ICTSUBJ: d = 0.121) are negligibly small according to Cohen's (1988) criteria, indicating that practical significance remains highly limited. This finding highlights that statistical significance does not guarantee practical meaningfulness in large samples

RQ3: Predicting Math Achievement

A Rubin pooled multiple regression analysis was conducted to determine whether ICT self-efficacy and subject-related ICT use significantly predicted mathematics achievement when socioeconomic status and gender were controlled for. The findings are presented in Table 3.

Table 3
Results of Rubin Pooled Regression Analysis Regarding the Prediction of Mathematical Achievement

Variable	B	Robust SE	t	p	β
Intercept	482.169	1.990	242.354	< .001***	
ICT Self-Efficacy (ICTEFFIC)	6.284	1.060	5.926	< .001***	0.080
Subject-Related ICT Use (ICTSUBJ)	12.109	0.995	12.175	< .001***	0.146
ESCS (control)	24.293	0.934	26.019	< .001***	0.316
Gender (control)	5.522	2.248	2.456	.015*	0.020
R^2 = .156 Explained variance = %15.6					

*Note: B = unstandardized regression coefficient; β = standardized beta coefficient; Robust SE = consistent standard error of HC3 heteroskedasticity; pooled using Rubin's (1987) rules. Since both ICT variables are scaled by IRT according to the OECD with mean=0, SD=1, the B coefficients are directly comparable using the same scale unit. *** p < .001, * p < .05.*

As shown in Table 3, the model explains 15.6% of the variance in mathematics achievement (R^2 = .156). When ESCS was controlled for and the effect of gender was removed, both ICT self-efficacy (B = 6.284, Robust SE = 1.060, t = 5.926, $p < .001$) and the use of ICT for learning purposes (B = 12.109, Robust SE = 0.995, t = 12.175, $p < .001$) were found to be significant predictors of mathematics achievement.

When the relative power of the predictor variables is examined, it is noteworthy that the use of ICT for learning purposes (B = 12.109, β = 0.146) is associated with an approximately twofold increase in mathematics achievement compared to ICT self-efficacy (B = 6.284, β = 0.080). When the control variables were examined, ESCS was found to be the strongest predictor (B = 24.293, β = 0.316, $p < .001$). Although the effect of gender was significant (B = 5.522, β = 0.020, $p = .015$), it remained quite limited.

DISCUSSION

This study investigated the predictive power of ICT self-efficacy (ICTEFFIC) and subject-related ICT use in lessons (ICTSUBJ) on mathematics achievement, controlling for socioeconomic status and gender, using Rubin pooled multiple regression analysis with PISA 2022 Türkiye data (n = 6,599). Both variables were identified as significant and positive predictors; the predictive effect of ICTSUBJ (B = 12.109) was found to be approximately twice as strong as that of ICTEFFIC (B = 6.284). The findings are discussed below within the context of the research questions, relevant literature, and theoretical framework.

The Effect of ICT Self-Efficacy (ICTEFFIC) on Mathematical Achievement

The first key finding of the study is that ICT self-efficacy (ICTEFFIC) significantly predicts mathematical achievement (B = 6.284, β = 0.080, $p < .001$). This finding is an expected pattern within the framework of Bandura's (1997) Social Cognitive Theory; self-efficacy belief directly shapes an individual's ability to persevere when faced with difficulty, to use cognitive resources efficiently, and to exhibit strategic learning behaviors. Students with a high self-efficacy perception in the digital context use technology more purposefully and resiliently, which reinforces cognitive processes that support mathematical learning (Bandura, 1997; Örnek & Afari, 2026).

This finding directly aligns with the PLS-SEM study conducted by Örnek & Afari (2026) using PISA 2022 Türkiye data (N = 7,250): in that study, ICTEFFIC positively predicted mathematics achievement at the level of β = .216 ($p < .001$). Li & Zhu (2023) showed that cognitive-motivational ICT involvement — of which ICTEFFIC is a key component — had a significant positive effect on student-level achievement in a multi-level structural equation modeling study covering 52 countries (β = .191, $p < .001$). Fayda-Kınık and Çetin's (2025) three-level HLM analysis covering 53 countries also revealed that perceived ICT competence (COMPICT) and ICT interest (INTICT) were positive predictors in the high achievement group; in contrast, the study found that social interaction-focused ICT use (SOIAICT) consistently negatively impacted achievement across all achievement quartiles. This finding highlights that the type of ICT engagement—whether competency-focused or social interaction-focused—is a key determinant of the impact on academic outcome; consistent with this pattern, given that ICTEFFIC represents the competency dimension in the present study. Hatlevik et al. (2018), in their International Computer and Information Literacy Study (ICILS) 2013 analysis covering 14 countries, also found that ICT self-efficacy positively predicted computer and information literacy achievement in all countries, including Türkiye (r = 0.17–0.36; r = 0.24 for Türkiye), and that the variance it explained was higher in Türkiye compared to other countries ($R^2 = 0.15$).

When evaluated within the framework of Digital Engagement Theory (Zylka et al., 2015; Kunina-Habenicht and Goldhammer, 2020), the expanded formulation of ICTEFFIC in PISA 2022 encompasses both core Computer and Information Literacy (CIL) tasks and computational thinking (CT) skills (OECD, 2024). At this point, the interesting finding obtained by Hristov et al. (2026) in the Finnish sample (N = 10,239) is noteworthy: CIL self-efficacy showed a strong positive correlation with success (β = .440–.528), while CT self-efficacy was negatively correlated with success (β = −.214 to −.334). This contrasting pattern suggests that using ICTEFFIC as a holistic index may mask some nuances; The question of whether CIL and CT skills influence academic achievement through different mechanisms, and whether this divergence is also valid in the Turkish sample, is an important question for future studies, and should be investigated through sub-dimension level analyses.

The relatively modest B coefficient of ICTEFFIC (B = 6.284, β = 0.080) indicates that digital self-efficacy belief needs to be transformed into a concrete usage behavior in a pedagogical context in order to produce academic output. Li and Zhu (2023) showed that ICT use affects student achievement not directly but largely through mediation via cognitive-motivational ICT engagement; this finding theoretically explains why psychological competence alone is insufficient and why ICTSUBJ is a stronger predictor than ICTEFFIC.

The Effect of Subject-Related ICT Use in Lessons (ICTSUBJ) on Mathematics Achievement

The second finding of the study is that the subject-related ICT use in lessons (ICTSUBJ) strongly and significantly predicts mathematics achievement ($B = 12.109$, $\beta = 0.146$, $p < .001$). This effect size is approximately twice that of ICTEFFIC in the model and empirically supports a growing line of literature: that it is not "how much ICT is used" but "in what pedagogical context ICT is used" that determines academic achievement (Zylka et al., 2015; Papanastasiou, Zembylas & Vrasidas, 2003).

This finding can be considered a continuation of the ICTCLASS finding from the hierarchical regression analysis conducted by Unal et al. (2022) with PISA 2018 Türkiye data ($n = 6,101$), extending to PISA 2022: in that study, subject-focused ICT use during lessons (ICTCLASS) positively predicted mathematics achievement at the $\beta = 0.18$ level ($p < .001$); it rose to the position of the strongest positive ICT predictor both among the ICT use variables and in the entire model. In the SEM analysis of PISA 2018 Türkiye data by Acun Çelik et al. (2024), subject-specific ICT use (SUB_ICT) also positively predicted mathematics achievement at the $\beta = 0.23$ level, becoming the strongest ICT variable in the model. Using PISA 2022 Australian data, Wei and Zhang (2025) also reported that ICTSUBJ positively predicted mathematics achievement ($\beta = 0.067$). This consistent pattern demonstrates that the benefits of subject-related in lessons ICT use are not limited to a single country or PISA cycle.

However, this finding does not entirely align with the relevant literature, and this discrepancy needs to be honestly addressed. Courtney et al. (2022), in their three-level HLM analysis covering the PISA 2009–2018 cycles, found that the use of subject-focused ICT during lessons (ICTCLASS) was negatively correlated with mathematics achievement ($b = -1.10$, $p < .001$). Hu et al. (2018), on the other hand, showed that the use of general ICT in schools (USESCH) was strongly negatively correlated with achievement in 44 countries ($\gamma = -9.67$, $p < .001$). Two main arguments can be put forward to explain this discrepancy. First, the PISA 2022 ICTSUBJ index was redesigned to measure curriculum-integrated use for specific subject and lesson objectives, qualitatively differing from the general in-school use measures of previous cycles; therefore, the difference between the findings may largely stem from the variables representing different pedagogical realities. Secondly, while the studies in question use multilevel modeling (HLM), the current research applies single-level regression; the inability to control grouping effects at the school and class level could potentially affect the direction and magnitude of the ICTSUBJ coefficient. This methodological difference should be tested with multilevel analyses in the future.

In Petko et al.'s (2017) PISA 2012 analysis covering 39 countries, it was found that the frequency of ICT use in schools was a negative predictor in 37 countries for academic achievement, while positive student attitudes toward the pedagogical usefulness of technology as a learning tool (ICTATTPOS) remained positively correlated with success in the vast majority of countries; this finding strengthens the argument that quality, rather than quantity, is the determining factor. When evaluated from the perspective of Self-Determination Theory (Deci & Ryan, 1985; Ryan & Deci, 2017), it can be argued that the use of ICT integrated into the curriculum and directed towards specific subject objectives supports students' needs for competence and autonomy, thereby increasing intrinsic motivation and positively impacting academic outcomes; However, it should be noted that this mechanism has not been experimentally tested in the PISA 2022 Türkiye data.

Comparative Interpretation of ICTEFFIC and ICTSUBJ

The finding that ICTSUBJ (B = 12.109, β = 0.146) is approximately twice as strong a predictor as ICTEFFIC (B = 6.284, β = 0.080) constitutes the most original theoretical contribution of this research. This difference provides empirical evidence that digital self-efficacy needs to be translated into concrete behavioral use in a pedagogical context in order to produce academic output. In other words, having a high self-efficacy belief has limited academic value unless that belief is reflected in purposeful and structured ICT use in the classroom. This finding is consistent with the core prediction of Digital Engagement Theory (Kunina-Habenicht and Goldhammer, 2020): that technology use contributes positively to success not only through cognitive or motivational factors, but through integrated processes where these factors are combined with behavioral engagement. Li and Zhu (2023), based on data from 52 countries, demonstrated that cognitive-motivational ICT engagement is a critical mediating mechanism bridging the gap between ICT use and success. Hristov et al. (2026) also showed that in Finland, the direct effect of ICT use for learning purposes on success was insignificant; however, the indirect effect through CIL self-efficacy was positive, emphasizing the need for tightly integrating ICT use with specific learning objectives. When all these findings are considered together, it is understood that the beta difference between ICTEFFIC and ICTSUBJ represents the transition point between psychological capacity and pedagogical practice.

The Determinant Role of Socioeconomic Status

The finding that ESCS (B = 24.293, β = 0.316, $p < .001$) is the strongest predictor in the model aligns with a long-documented and internationally replicated pattern in educational research. This value is approximately twice the ICTSUBJ effect and four times the ICTEFFIC effect, clearly demonstrating the decisive dominance of socioeconomic structure on academic achievement. PISA 2022 Türkiye findings show that the relationship between socioeconomic inequality and mathematics achievement is significantly above the OECD average (OECD, 2023).

Hu et al.'s (2018) analysis of PISA 2015 in 44 countries revealed that SES maintained its position as the strongest predictor of achievement at both individual and school levels. Hatlevik et al.'s (2018) findings also show that SES continues to be the primary driver of the digital divide; The study showed that ICT self-efficacy significantly predicted success even after controlling for SES. The fact that the current research predicts ICT variables while statistically controlling for SES is important because it reveals that these relationships exist independently of socioeconomic status. However, whether ICTEFFIC and ICTSUBJ are equally strong predictors for students in different SES groups remains an important question awaiting investigation through moderation or multi-level analysis.

Interpretation of Gender Findings

The gender findings of the study necessitate careful evaluation. The significant gender coefficient in the regression model (B = 5.522, β = 0.020, $p = .015$) indicates a mathematics achievement pattern in favor of female students; on the other hand, the effect sizes of the gender differences observed in ICT variables (ICTEFFIC: $d = 0.069$; ICTSUBJ: $d = 0.121$) remain negligible according to Cohen's (1988) criteria.

The statistically significant difference of male students in ICT variables stems from the fact that even very small differences produce significant p-values in a large sample size of n = 6,599, and it is methodologically necessary not to disregard effect sizes. In Hatlevik et al.'s (2018) analysis covering 14 countries, it was found that the gender difference in ICT self-efficacy in Türkiye was insignificant ($p > .05$); This finding is consistent with the negligible effect sizes in the current study. Hristov et al. (2026) showed that the structural effects of ICT self-efficacy on achievement did not differ for both girls and boys in Finland. Kunina-Habenicht and Goldhammer (2020) reported that in PISA 2015 data from Switzerland and Germany, female students exhibited lower latent means than male students in the dimensions of perceived ICT competence and ICT autonomy. Whether this pattern is observed in the Turkish sample and whether the reflection of the ICT self-efficacy gap on mathematics achievement differs for girls compared to boys is a question that needs to be investigated with moderation analyses.

Unique Assessment in the Context of Türkiye

The fact that the average ICT self-efficacy of students in Türkiye almost coincides with the OECD average (≈ 0) (Mean = 0.011) indicates that current infrastructure investments are partially reflected in student perceptions. However, the way these investments translate into pedagogical practice at the classroom level — which ICTSUBJ measures — maintains its decisive position on mathematics achievement. When the findings of three consecutive PISA cycles in Türkiye are evaluated together, a consistent pattern emerges. In Bulut and Cutumisu's (2018) PISA 2012 analysis, in-school computer use (USESCH) negatively predicted mathematics achievement ($\beta = -0.107$). In Unal et al.'s (2022) PISA 2018 analysis, while general in-school ICT use (USESCH) continued to negatively predict achievement, in-class subject-focused ICT use (ICTCLASS) became the strongest positive ICT predictor in the model ($\beta = 0.18$). In the present study, the strong positive effect of ICTSUBJ ($B = 12.109$, $\beta = 0.146$) on PISA 2022 data continues this pattern. Örnek and Afari's (2026) findings on the same PISA 2022 Türkiye data also confirm the strong positive predictor of digital self-efficacy and the negative trend of general ICT use in schools. This three-cycle integrity supports the idea that unstructured general ICT use in Türkiye consistently has a limited or negative academic impact; however, its use for educational purposes and integrated into the curriculum can offer a positive contribution, suggesting that policy priority should be directed towards the technological professional development of teachers and the integration of technology into the curriculum, in addition to hardware acquisition.

Model Explanatory Power and Methodological Limitations

The regression model explaining 15.6% of the variance ($R^2 = .156$) is consistent with single-sectional PISA analyses conducted with similar sets of variables in the literature; indeed, Wang et al.'s (2023) systematic review of 156 articles showed that the vast majority of factors used in studies addressing PISA mathematics achievement produce complex and variable explanatory rates.

Methodological strengths can be listed as follows: 10 plausible values were pooled according to Rubin's (1987) rules; robust HC3 standard errors were used in response to the heteroskedasticity problem identified by the Breusch-Pagan test; and the large sample size ($n = 6{,}599$) increased the reliability of parameter estimates.

The main limitations of the study must also be honestly acknowledged. First of all, the cross-sectional design does not allow for causality inference; the relationship between ICT self-efficacy and mathematics achievement may be bidirectional. Secondly, the elimination of missing data using the listwise deletion method carries the risk of selection bias; the multiple assignment method may offer a more robust alternative to mitigate this limitation. Thirdly, PISA's self-report-based measurement structure carries the risk of common method variance. Fourthly, it should be noted that the one-level regression model does not account for the clustering effects at the school and district levels; multi-level modeling approaches would offer a more suitable analytical framework to overcome this limitation; as a specific consequence of this limitation, the magnitude of the ICTSUBJ coefficient may differ when school-level variations are controlled. Finally, ICTSUBJ is modeled using linear terms, and the possible threshold effect — an inverted U-relation where moderate use is beneficial and excessive use is harmful — shown by Li and Zhu (2023) and Zhu and Li (2022) could not be tested in this study; it is suggested that future research should test this relationship through quadratic terms.

CONCLUSION

This study, using Rubin pooled multiple regression analysis with PISA 2022 Türkiye data, revealed that digital self-efficacy (ICTEFFIC) and classroom-oriented ICT use (ICTSUBJ) are significant predictors of mathematics achievement, even when controlling for socioeconomic status and gender. The findings are consistent with the core predictions of Digital Engagement Theory (Zylka et al., 2015; Kunina-Habenicht & Goldhammer, 2020) and Self-Determination Theory (Deci & Ryan, 1985; Ryan & Deci, 2017): psychological competence and pedagogical action are complementary but relatively different predictors. The strong impact of ICTSUBJ in particular ($B = 12.109$, $\beta = 0.146$) confirms that for digital technologies to positively contribute to academic outcomes, they must go beyond mere access or self-efficacy perception and transform into a pedagogically meaningful form of use integrated into the curriculum in the classroom environment. The pattern obtained from three consecutive PISA cycles in Türkiye reinforces this message. It is recommended that future research examine the ICT-achievement relationship using multi-level models, longitudinal designs, nonlinear specifications, and moderation analyses according to socioeconomic status (SES) groups; and test whether the inverse effects between the CIL and CT sub-dimensions of ICTEFFIC are also valid in the Turkish context.

Ethical Statement

This study is an original and independent research article; it has not been derived from any master's/doctoral thesis, nor has it been previously presented or published elsewhere.

Ethics Committee Approval

Ethics Committee Approval is not required for this study, as it constitutes a secondary data analysis utilizing the publicly available, de-identified, and anonymized dataset from the Program for International Student Assessment (PISA) 2022 administered by the OECD

Author Contributions

The sole author (Elif Nur Bozer Özsaraç) was responsible for the research design (CRediT 1), data collection (CRediT 2), research, data analysis, and validation (CRediT 3-4-6-11), writing the article (CRediT 12-13), as well as the revision and improvement of the text (CRediT 14).

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

Sustainable Development Goals (SDG)

Sustainable Development Goals: 4 Quality Education

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