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Self-directed learning self-efficacy in mathematics: The role of anxiety, support, and contextual factors

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ABSTRACT

This study examines individual and environmental factors predicting self-directed learning (SDL) self-efficacy among 15-year-old students and investigates the interaction between math anxiety and teacher support. Using nationally representative data from 5,515 students in the PISA 2022 Türkiye sample, weighted logistic regression analysis was employed to estimate the probability of students demonstrating above-average SDL self-efficacy. Missing data were addressed through multiple imputation, and sampling design effects were taken into account. The results indicate that twenty-first-century mathematics self-efficacy, family support for learning, and perseverance in mathematics substantially increase the likelihood of high SDL self-efficacy. In contrast, math anxiety is negatively associated with SDL self-efficacy and shows a significant interaction with teacher support. Specifically, the negative association between math anxiety and SDL self-efficacy was negligible when perceived teacher support was low; however, this negative association became substantially stronger at higher levels of teacher support. Additionally, mathematical motivation and perceiving mathematics as easy are unexpectedly associated with lower SDL self-efficacy. Overall, the findings highlight the importance of contextual and affective factors, alongside individual beliefs, in shaping students' SDL capacities. This unexpected pattern suggests that the predominantly instructional teacher support measured in PISA may not buffer the adverse correlates of math anxiety but may instead amplify them, possibly because directive and controlling support styles increase performance pressure for anxious students. These results have important implications for educational practice and teacher preparation aimed at fostering students' autonomy and self-efficacy in learning.

Contribution/Originality: This study contributes to existing literature by modeling individual and environmental predictors of SDL self-efficacy using a nationally representative PISA 2022 dataset. This study is one of the very few studies that have investigated the moderating role of teacher support on the mathematics anxiety–SDL self-efficacy relationship. The paper's primary contribution is finding that instructional teacher support amplifies, rather than buffers, the negative association between math anxiety and SDL self-efficacy.

1. INTRODUCTION

In today's knowledge society, individuals' lifelong learning capacities and their ability to independently manage their learning processes have become not only an academic requirement but also a fundamental life skill. Conceptualized as self-directed learning (SDL), this skill is defined as a process in which individuals take the initiative to identify their learning needs, set learning goals, determine resources for achieving those goals, select and apply appropriate learning strategies, and evaluate learning outcomes without the help of others (Knowles, 1975). SDL skills are considered fundamental goals of education systems worldwide (Boyer, Edmondson, Artis, & Fleming, 2014), and the rapid changes brought about by digitalization and artificial intelligence have further reinforced the need for learners who can independently evaluate and manage information. The COVID-19 pandemic has once again highlighted how critical these skills are for students' academic resilience and their ability to continue learning in the face of uncertainty (OECD, 2021). Research has confirmed that distance learning during this period positively influenced SDL skills and motivation (Almomani, Halalsheh, Al-Dreabi, Al-Hyari, & Al-Quraan, 2023), underscoring SDL as essential for academic continuity.

Large-scale studies such as the Programme for International Student Assessment (PISA) provide valuable data for comparatively evaluating the extent to which education systems impart this fundamental skill to students. The PISA 2022 cycle is particularly significant, as it captured the educational reflections of the post-pandemic period (OECD, 2023). Self-efficacy in mathematics is especially important for students' academic futures (Manaud & Aggabao, 2024). Türkiye's PISA 2022 mathematics score of 453 fell below the OECD average of 472 (Ministry of National Education, 2023), indicating that a significant proportion of students experience difficulties in acquiring basic mathematical competencies and necessitating an examination of the underlying affective and environmental factors.

Within the context of Social Cognitive Theory (Bandura, 1997) and Ecological Systems Theory (Bronfenbrenner, 1979), which shape the theoretical framework of this study, it is known that the social and affective contexts in which students identify themselves are decisive in the learning process. These theories approach learning not only as an individual action but also as a dynamic process in which the individual is in constant interaction with their environment. From the social cognitive theory perspective, self-efficacy functions as a threshold: individuals either believe they can accomplish a given task or they do not, and this belief directly shapes their behavior (Bandura, 1997). This theoretical framework informed the binary operationalization of SDL self-efficacy in the present study, reflecting the qualitative distinction between students who perceive themselves as capable self-directed learners and those who do not. Ecological Systems Theory (Bronfenbrenner, 1979), on the other hand, posits that individual learning outcomes are shaped by multiple nested environmental layers. The relative contribution of different ecological levels, such as the microsystem and mesosystem, should be determined empirically from the data rather than assumed in advance. Therefore, in this study, the variables predicting self-efficacy in mathematics were selected using a holistic approach that includes both individual and environmental factors. Among these factors, the negative role of affective barriers, such as math anxiety, in learning processes is well known. Meta-analyses have demonstrated a stable and adverse correlation between math anxiety and mathematical performance ($r = -.28$) (Barroso et al., 2021). More importantly, it has been found that math anxiety tends to increase developmentally from middle school to high school and peaks during adolescence (Devine, Hill, Carey, & Szűcs, 2018; Sorvo et al., 2019). This situation makes it particularly important to understand how math anxiety hinders the development of critical competencies such as problem-solving in 15-year-old students, the target group of PISA.

Furthermore, the question of how environmental resources, such as supportive teacher-student relationships, can mitigate this negative effect represents an area that warrants further empirical investigation. There is a growing body of evidence in the literature suggesting that teacher support plays a mitigating role in students' academic stress and anxiety levels (Palmwood, 2024; Wang, Xu, & Fei, 2024). Palmwood (2024) empirically demonstrated that a strong teacher-student relationship mitigates the negative impact on academic performance, particularly for students experiencing moderate levels of math anxiety. Wang et al. (2024) similarly discovered that perceived teacher support indirectly alleviates math anxiety by fostering a positive teacher-student relationship and enhancing math self-efficacy. These findings strengthen the hypothesis that teacher support not only creates a direct positive effect but can also moderate or mediate the harmful effects of negative affective experiences, such as anxiety, on academic outcomes.

There is a scarcity of studies in the literature that offer direct and probabilistic evidence regarding the buffering role of teacher support in alleviating the adverse impact of math anxiety on self-efficacy. Despite growing interest in SDL, no study to date has used large-scale, nationally representative data to simultaneously model individual and environmental predictors of SDL self-efficacy while empirically testing the moderating role of teacher support on the anxiety–self-efficacy link using a survey-adjusted probabilistic framework. To fill this scientific gap, the study aims to establish a probabilistic model of the relationships between factors predicting self-efficacy in mathematics, utilizing the PISA 2022 Türkiye sample.

The main research problem of this study is to identify the individual and environmental factors that predict the probability of 15-year-old students in the PISA 2022 Türkiye sample having above-average self-efficacy in mathematics and to model the relationships between these factors. Within the framework of this main problem, answers were sought for the following subproblems:

1. Do students' gender, motivational tendencies, mathematical self-efficacy beliefs, and perceptions of the learning environment significantly predict their likelihood of having above-average SDL self-efficacy?
2. Does perceived teacher support statistically significantly moderate the negative effect of math anxiety on the likelihood of students having above-average SDL self-efficacy?

In particular, Türkiye's PISA results falling below the OECD average (Ministry of National Education, 2023) and the relatively high levels of math anxiety among students in Türkiye (TEDMEM, 2024; Yenilmez & Özabacı, 2003) increase the importance of this study's findings in terms of national education policies. The study aims to fill an important gap in the literature by empirically testing the potential moderating role (interaction term) of teacher support on the negative impact of math anxiety. The results are expected to provide a concrete and evidence-based foundation for enriching teacher education programs, strengthening classroom support mechanisms, and developing interventions targeting students' affective needs.

2. METHOD

2.1. Research Model and Participants

This study employs a cross-sectional, correlational design using PISA 2022 and focuses on factors associated with students' self-efficacy. Accordingly, the analyses are framed as probabilistic associations rather than causal effects. Because the outcome was operationalized as a binary variable, we estimated a logistic regression model to quantify the associations between the predictors and the outcome. The target population comprised 15-year-old students in Türkiye who participated in PISA 2022. In total, 7,250 students from 196 schools took part in the PISA 2022 administration in Türkiye. The Türkiye sample was selected via a stratified two-stage probability design: schools were first sampled with probability proportional to size within strata defined by geographic region and school type, and students were then randomly selected within the sampled schools. Missing values on analysis variables were handled through multiple imputation. Following this procedure, 10 imputed datasets were generated based on 5,515 students with valid responses on the dependent variable. Outlier screening and any necessary corrections were conducted separately for each imputed dataset. Model estimation and pooling were then carried out using an average analytic sample of 4,956 students from 194 schools. The mean age of the analytic sample was 15.8 years, with 50.4% female and 49.6% male students. Given PISA's stratified sampling framework, the resulting analytic sample largely preserves the representativeness of Türkiye's 15-year-old student population.

2.2. Variables and Data Collection Tools

All variables in this study are based on indices derived from student responses in the PISA 2022 Türkiye sample. The study utilized one dependent variable and independent variables grouped into three main categories.

2.2.1. Dependent Variable

SDL Self-Efficacy: These variables measure students' self-efficacy in performing various SDL tasks. In PISA 2022, this construct was measured using eight items; students selected one of four levels of self-confidence for each item. Although the index is a continuous variable, dividing it into two categories provides practicality and ease of interpretation. This dichotomization can be justified for three reasons. First, Bandura (1997) describes self-efficacy as a construct that may operate in a threshold-like way: students who believe they can succeed and those who do not may differ not only in degree, but also in the quality of their behavior. Dichotomization, therefore, captures a theoretically meaningful distinction. Second, the PISA index is centered at 0 (the OECD average), which provides a meaningful external cut point rather than an arbitrary median split. Finally, from a policy and practice standpoint, identifying students as above or below the international average in SDL self-efficacy provides a clearer and more actionable basis for educational decision-making. Accordingly, students with an index score below 0 were classified as having 'below average' (0) self-efficacy, while those with a score above 0 were classified as having 'above average' (1) self-efficacy.

2.2.2. Independent Variables

2.2.2.1. Factors Related to the Teaching and Learning Environment

Exposure to 21st-Century Skills is an index indicating how frequently students encounter 21st-century mathematics tasks at school. It comprises ten items rated on a four-point scale. Higher scores reflect more frequent exposure to school-based activities emphasizing mathematical reasoning and applied problem solving.

Teacher Support in Mathematics is an index capturing how often students perceive supportive teaching practices in mathematics classes. It is based on four items rated on a four-point response scale, with higher scores indicating more frequent and stronger perceived support.

Quality of Student–Teacher Relationship is an index reflecting students' overall perceptions of the teacher–student relationship at school. It is derived from eight statements rated with four response options, where higher scores indicate a higher-quality relationship.

2.2.2.2. Emotional/Motivational/Self-Efficacy Factors

Math Anxiety is an index representing students' anxiety related to mathematics learning and performance. It consists of six items rated with four response options, and higher scores indicate greater anxiety.

Expected Highest Level of Education is an ordered index created from students' reported educational expectations, ranging from below ISCED level 2 to ISCED level 8. This variable was created for PISA 2022.

Mathematical Self-Efficacy is an index indicating students' confidence in performing a range of formal and applied mathematics tasks. It comprises nine items rated on a four-point Likert-type scale, with higher scores reflecting stronger self-efficacy.

21st-Century Mathematics Self-Efficacy is an index assessing students' confidence in mathematical reasoning and contemporary mathematics tasks. It includes ten items rated on a four-point scale, where higher scores indicate higher self-efficacy.

Proactive Math Study Behavior is an index capturing how often students report effortful and persistent study behaviors in mathematics. It is measured with eight items using a five-point Likert-type scale, and higher scores indicate more frequent proactive behavior.

Relative Motivation to Be Better at Math is a binary indicator comparing students' motivation for mathematics with their motivation for Turkish and science. Students are coded as 1 when motivation for mathematics exceeds motivation for both other subjects; otherwise, they are coded as 0.

Perceiving Math as Easier Compared to Other Core Courses is a binary indicator capturing whether students perceive mathematics as easier than Turkish and science. Students are coded as 1 when mathematics is perceived as easier than both other subjects; otherwise, they are coded as 0.

2.2.2.3. Social Support / Family / Environmental Factors

Family Support for SDL is an index summarizing how often students reported receiving family support for self-directed learning during COVID-19 school closures. It is based on eight items rated with four response options, with higher scores indicating greater family support.

Problems Experienced in SDL is an index summarizing how often students reported experiencing difficulties while completing school assignments during COVID-19 school closures. It comprises eight items rated with four response options, and higher scores indicate more frequent problems.

2.2.2.4. Demographic/Control Variables

Gender: Categorically coded as female students (0) and male students (1).

Standardization and coding are the procedures whereby all continuous variables were converted to z-scores to facilitate interpretation, such that coefficients reflect the effect of a one-standard-deviation increase in the predictor. Categorical variables were dummy-coded and included in the models with their reference categories.

2.3. Data Analysis Process

Data analyses were performed using R software (version 4.5.0; R Core Team (2024)) and the RStudio development environment (version 2024.04.2; RStudio Team (2024)). To address missing data in the variables included in the analysis, Little's MCAR test was first applied. Since the test result was significant ($p < 0.001$), it was assumed that the missing data were not completely at random. Therefore, instead of methods such as listwise deletion or mean imputation, multiple imputation was preferred, as it reduces bias arising from missing data while preserving statistical power. Ten complete data sets were created using predictive mean matching and logistic regression methods. Observations with missing data in the dependent variable were excluded from the analysis as recommended (Allison, 2002). To increase the robustness of the model, Cook's distance, leverage values, and standardized residuals were examined on each created dataset to identify influential observations, and the identified influential observations were removed from each dataset. Taking into account the stratified and clustered sample structure of the PISA data, Fay's balanced repeated sampling (BRR; $\rho = 0.5$) method was used in the analyses, using student final weights and 80 replication weights. Logistic regression models were established using this complex design on each assigned and cleaned dataset. Logistic regression models were established that predicted the main effects, and the interaction term "math anxiety × teacher support" was determined based on the theoretical framework, which predicted the probability of students having above-average self-efficacy in math. Model coefficients and variance-covariance matrices obtained separately for all data sets were combined using Rubin's rules (Rubin, 1987). Three different weighted logistic regression models were established using a hierarchical approach to model the factors predicting SDL self-efficacy and the relationships between them.

Model 1 (Null Model): This model is a basic model containing only the intercept term and no independent variables. It was used to estimate the between-school variance (Intraclass Correlation Coefficient, ICC) to decide whether a multilevel model was necessary.

Model 2 (Main Effects Model): All main predictor variables related to demographics, affective factors, motivation, teaching, and family support were added to this model. Thus, the effects of factors that could directly influence the probability of having above-average SDL self-efficacy were tested.

Model 3 (Interaction Model): In addition to Model 2, the interaction term "math anxiety × teacher support" was added. Since there are strong expectations in the literature that teacher support can reduce the negative effects of anxiety, this interaction was specifically tested.

The null model yielded an ICC of approximately 2%, indicating that only a small proportion of the variance in SDL self-efficacy was attributable to between-school differences. Although even small ICC values can justify multilevel modeling in large-scale datasets, Fay's BRR with 80 replication weights produces cluster-robust standard errors that account for both stratification and clustering effects, thereby addressing the hierarchical data structure through design-based inference (Lumley, 2010; Rust & Rao, 1996). Accordingly, the single-level survey-weighted model was determined to be the most parsimonious and appropriate approach for the present study.

The assumptions of logistic regression analysis were systematically tested. The linearity assumption between continuous predictor variables and the logit value of the outcome variable was examined using the Box-Tidwell test. According to pooled results, the fact that none of the log terms were significant ($p > 0.05$) for the main continuous predictors indicated that the linearity assumption was met. The problem of multicollinearity was controlled using the Variance Inflation Factor (VIF) values, and the VIF < 5 criterion was met for all variables. Since the analyses were conducted using svyglm (Quasibinomial) and Fay-BRR resampling weights, the standard errors were design-based and robust against over-dispersion.

3. RESULTS

3.1. Descriptive Statistics

Pooled descriptive statistics for all continuous variables included in the analysis are presented in Table 1. The means of the variables are close to 0, and the standard deviations are close to 1. The skewness and kurtosis values indicate that the variables do not deviate excessively from a normal distribution. The wide minimum-maximum range of each variable shows that the research group has a heterogeneous structure in terms of these characteristics and includes a wide variety of student profiles. In particular, the wide variation in the variables of teacher-student relationship quality and expected educational level indicates that students have different experiences regarding educational support and expectations. This diversity indicates that the research was conducted on a heterogeneous sample and increases the applicability of the results to different student groups.

Table 1. Pooled Descriptive Statistics for Continuous Variables (N = 5515; 10 imputations).

Variables	Mean	SD	Min.	Max.	Skewness	Kurtosis
Teaching/Learning Environment						
Exposure to 21st-Century Skills	0.01	0.98	-2.64	3.02	0.12	0.79
Teacher Support	0.00	0.98	-2.35	1.60	-0.10	-0.08
Teacher-Student Relationship Quality	0.00	0.98	-5.7	3.05	-0.06	2.86
Emotional/Motivational/Self-Efficacy Factors						
Mathematics Anxiety	0.01	0.99	-2.46	1.68	-0.19	0.13
Expected Education Level	0.02	0.97	-3.35	1.05	-1.14	0.95
Mathematics Self-Efficacy	0.04	0.99	-2.41	2.24	-0.23	0.71
21st Century Mathematics Self-Efficacy	0.01	0.98	-2.37	2.60	-0.07	0.34
Perseverance in Mathematics	0.01	0.98	-2.83	2.81	0.06	1.08
Social Support / Family / Environmental Factors						
Family Support for SDL	-0.01	0.99	-2.46	2.14	-0.29	0.28
Family Support (General)	0.04	0.96	-2.62	1.97	0.09	-0.04
Problems Experienced in SDL	-0.03	0.98	-2.21	2.64	-0.17	0.24

3.2. Model Comparison

Table 2 presents the fit statistics for the three hierarchical models constructed to predict above-average self-efficacy in academic achievement. Model 1 (Null Model) showed that the variance between schools was approximately 2.0%. This value indicates that only a small portion of the total variance is between schools, and therefore, the majority of the variance stems from factors at the student level. Model 2 (Main Effects Model) provided a significant improvement in model fit compared to the empty model (Δ-2LL = 1016.8, $p < 0.001$). The explanatory power of the model was assessed using McFadden R^2 and Tjur R^2, as Cox and Snell R^2 and Nagelkerke R^2 values could not be calculated using the maximum likelihood estimation method, but were not supported by the svrepglm method. McFadden is 0.150, and Tjur is 0.187. These values indicate that the main effects model explains approximately 15-19% of the variance in the dependent variable. Model 3 (Interaction Model) was created by adding the interaction term between teacher support and math anxiety to Model 2. This model provided a statistically significant improvement, albeit small, compared to the main effects model. The slight increase in McFadden R^2 (0.151) and Tjur R^2 (0.189) values confirms that the interaction term makes a small but meaningful contribution to the model. Lower AIC and BIC values also indicate that Model 3 is the most data-consistent model. Therefore, final interpretations were made based on Model 3. Model 3 shows a statistically significant level of better fit compared to Model 2 ($\Delta\chi^2$ = 9.40, Δdf = 1, $p < 0.01$).

Table 2. Comparison of hierarchical logistic regression models.

Model	k (Parameter)	-2LL	AIC	BIC	ICC	McFadden R^2	Tjur R^2
Model 1	1	6856.00	6858.00	6872.50	0.02	-	-
Model 2	15	5839.20	5869.20	5966.80	-	0.150	0.187
Model 3	16	5829.80	5861.80	5965.90	-	0.151	0.189

Note: k = number of parameters. -2LL = -2 Log-Likelihood. AIC = Akaike Information Criterion. BIC = Bayesian Information Criterion. ICC = Intra-class Correlation. Lower -2LL/AIC/BIC values indicate better fit, while higher pseudo R^2 values indicate higher explanatory power.

3.3. Final Model Results

The study developed a weighted logistic regression model to determine the factors affecting SDL self-efficacy, which included all variables related to demographic information, learning environment characteristics, affective and motivational factors, and environmental factors. The Rubin-pooled logistic regression coefficients, standard errors, odds ratios (OR), and confidence intervals for the final model, Model 3, are presented in Table 3. These analysis results show which factors influence the likelihood of students having above-average SDL competence and in what direction.

Table 3. Final Logistic Regression Model (Model 3) Results (Pooled, N=5515, m=10).

Variables	B	S.E.	Wald χ^2	OR	95% CI	p
(Constant)	0.06	0.05	1.15	1.06	[0.95, 1.18]	0.283
Demographic						
Gender (Male)	-0.09	0.07	1.68	0.91	[0.79, 1.05]	0.195
Factors Related to the Teaching/Learning Environment						
Exposure to 21st Century Skills	0.13	0.04	10.21	1.14	[1.05, 1.23]	0.001
Teacher Support	0.01	0.04	0.12	1.01	[0.93, 1.11]	0.731
Teacher-Student Relationship Quality	0.16	0.04	14.78	1.18	[1.08, 1.28]	<0.001
Emotional/Motivational/Self-Efficacy Factors						
Mathematics Anxiety	-0.13	0.04	8.36	0.88	[0.81, 0.96]	0.004
Expected Education Level	0.15	0.04	12.72	1.16	[1.07, 1.26]	<0.001
Mathematics Self-Efficacy	0.12	0.05	5.14	1.12	[1.02, 1.25]	0.023
21st Century Mathematics Self-Efficacy	0.42	0.06	54.30	1.52	[1.36, 1.70]	<0.001
Perseverance in Mathematics	0.28	0.05	36.69	1.32	[1.21, 1.44]	<0.001
Mathematics Motivation (High)	-0.40	0.17	5.80	0.67	[0.48, 0.93]	0.016
Easy Math Comprehension (High)	-0.64	0.13	24.91	0.53	[0.41, 0.68]	<0.001
Social Support / Family / Environmental Factors						
Family Support for SDL	0.34	0.04	74.22	1.41	[1.31, 1.53]	<0.001
Family Support (General)	0.18	0.04	16.53	1.20	[1.10, 1.31]	<0.001
Problems Experienced in SDL	-0.14	0.04	12.98	0.87	[0.80, 0.94]	<0.001
Interaction effect						
Teacher Support × Math Anxiety	-0.09	0.04	5.69	0.91	[0.84, 0.98]	0.017

Note: The svyglm (quasibinomial) final model was fitted in each imputation set using Fay-BRR replication weights (80 reps., ρ=.5, mse=TRUE) and the TRIM application; coefficients and variances were pooled using Rubin pooling. Wald χ^2 values are given for df=1; since the interaction term has a single degree of freedom, it is reported directly as $(B/SE)^2$.

According to the findings of Model 3, 21st-century mathematics self-efficacy is the variable that most strongly increases the likelihood of having above-average self-efficacy. A one-standard-deviation increase in this variable increases the likelihood of above-average self-efficacy by approximately 1.52 times (OR=1.52). Similarly, family support for SDL (OR=1.41) and perseverance in mathematics (OR=1.32) are other important predictors that significantly increase the probability (by 41% and 32%, respectively). Conversely, as ease of understanding mathematics and motivation for mathematics increase, the likelihood of having above-average self-efficacy in SDL decreases. Students who perceive mathematics as easier than other subjects are 47% less likely to have high SDL self-efficacy in mathematics than those who do not (OR=0.53). Mathematics anxiety, as expected, is negatively associated with SDL self-efficacy in mathematics. A one-standard-deviation increase in anxiety reduces the likelihood of above-average SDL by approximately 12% (OR=0.88). However, this effect interacts with teacher support, and the nature of this interaction is examined in detail below.

3.4. Examination of the Interaction Effect

The statistically significant 'teacher support × math anxiety' interaction found in the model ($B = -0.09$, $p = 0.017$) indicates that the effect of math anxiety on self-efficacy varies depending on the level of teacher support (see Figure 1). Looking at the details, it can be seen that the direction of the effect of math anxiety on SDL self-efficacy changes depending on the level of teacher support. When teacher support is low (Here, absence or negativity is not mentioned), the relationship between math anxiety and SDL self-efficacy is almost horizontal, even slightly positive. In other words, an increase in anxiety level does not have a significant negative effect on self-efficacy, and it can be said that the expected negative effect is substantially attenuated. When teacher support is high, the situation is reversed. As math anxiety increases, the probability of above-average SDL self-efficacy decreases significantly. In statistical terms, the negative interaction coefficient ($B = -0.09$) indicates that each one-standard-deviation increase in teacher support adds -0.09 to the anxiety slope, making the anxiety–self-efficacy association progressively more negative. At low teacher support (-1 SD), the total conditional association of anxiety is $B = -0.13 + (-0.09 \times -1) = -0.04$, which is near zero. At high teacher support ($+1$ SD), the total conditional association becomes $B = -0.13 + (-0.09 \times +1) = -0.22$, representing a substantial negative association. This pattern indicates that teacher support, as measured in PISA (Predominantly instructional and directive in nature), does not buffer the negative correlates of math anxiety but rather amplifies them.

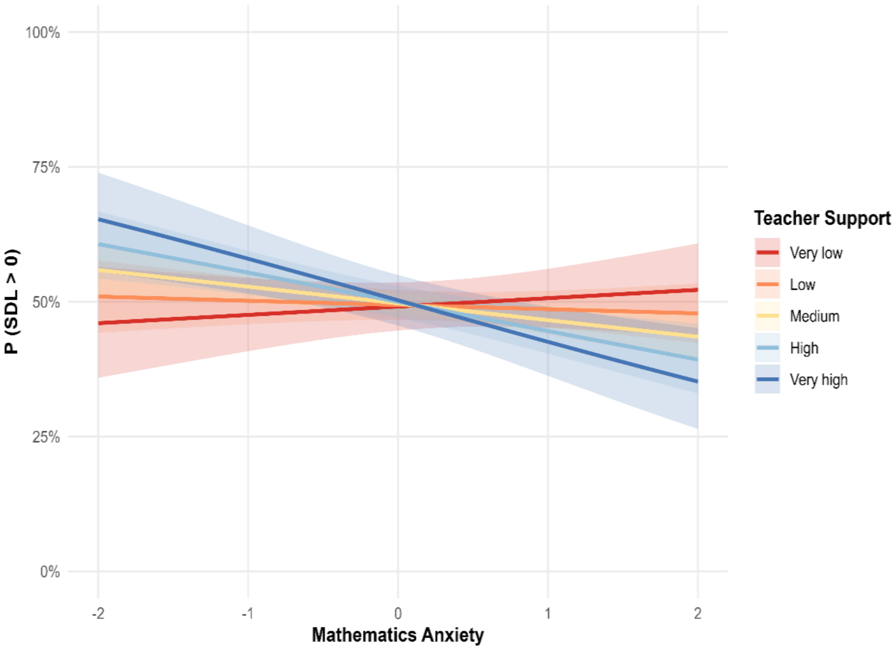

Figure 1. Interaction Effect of Teacher Support and Math Anxiety on SDL Self-Efficacy.

3.5. Model Fit and Diagnostic Statistics

Calibration and classification criteria were used as primary evidence of model validity. Binary outcomes (0/1) and categorical predictor levels were reviewed to check for categorical cell adequacy and sparse data assumptions, and no significant issues were found. The post-trim sample size is N = 4950, with an event rate of 50.2%. Since the final interactive model has k = 16 parameters, parameters per event" to "events per parameter ≈ 155." This value is well above the threshold (>= 10) commonly accepted in the literature (Peduzzi, Concato, Kemper, Holford, & Feinstein, 1996). The estimates are finite, the standard errors are of the usual magnitude, and no divergence was observed. The design-weighted calibration test also showed that the intercept is very close to 0 and the slope is very close to 1 (intercept ~ 0.000, SE ~ 0.040; slope ~ 1.000, SE ~ 0.034) (Hosmer, Lemeshow, & Sturdivant, 2013). The findings are consistent with cluster-robust standard errors and design-based Wald tests (White, 1980).

To evaluate predictive accuracy, we conducted ROC (Receiver Operating Characteristic) analysis (Fawcett, 2006). Figure 2 presents the averaged ROC curve, and the AUC ranged from 0.747 to 0.750 across the 10 imputed datasets (mean AUC = 0.748). These results indicate acceptable discrimination (Hosmer et al., 2013).

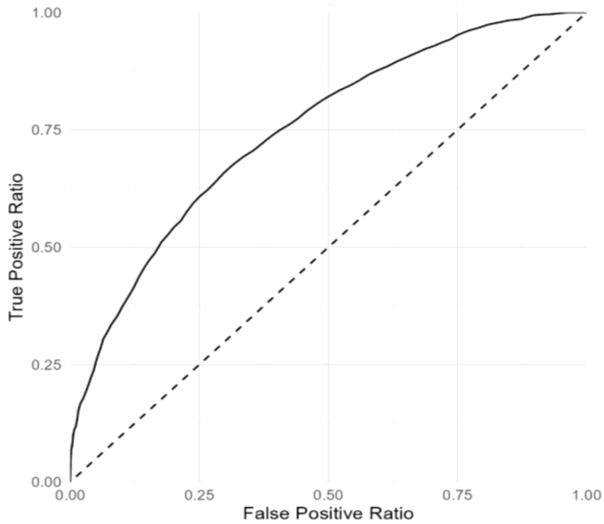

Figure 2. Pooled, Design-Weighted ROC Curve (AUC = 0.748).

Note: ROC and AUC are approximated using the mean between imputations. This is not a standard counterpart of Rubin pooling.

The model's classification performance showed a design-weighted accuracy rate of 68.0% based on the $p \geq 0.50$ threshold. This rate provides a relative improvement of 35.9% compared to the 50.1% majority class (Chance) accuracy in the same sample (Hosmer et al., 2013). The relative improvement was calculated using the formula [(Model accuracy - chance accuracy) / chance accuracy] × 100, as recommended in the literature. The balanced sensitivity (67.5%) and specificity (68.6%) values of the model indicate consistent success in distinguishing positive and negative cases (Fawcett, 2006). The Hosmer-Lemeshow goodness-of-fit test results for the model yielded a Fisher combined p-value of 0.108. Since $p > 0.05$, the model's fit between the predicted probabilities and the observed data was confirmed to be adequate (Hosmer & Lemesbow, 1980).

4. DISCUSSION

This study aimed to identify the factors affecting the probability of 15-year-old students having SDL self-efficacy above and below the mean, based on PISA 2022 data. According to the research results, gender is not a significant variable in self-efficacy. There is no consensus in the literature that gender creates differences in self-efficacy skills. Considering that skill development is a prerequisite for self-efficacy (Candy, 1991), it can be said that similar conclusions can be drawn for self-efficacy dimensions based on the findings related to SDL skills. This finding of the study contradicts previous studies showing that girls have intrinsic motivation in the context of SDL and behave more self-determined in academic self-regulation (Alivernini et al., 2018; Grouzet, Otis, & Pelletier, 2006). Similarly, it is inconsistent with findings reporting that boys have a higher perception of autonomy and competence than girls (Diseth, Breidablik, & Meland, 2018). However, there are also studies showing that gender does not create a significant difference in SDL skills. For example, Schweder and Raufelder (2021) found no significant difference between girls and boys in autonomy, competence, or forms of self-directed motivation (intrinsic motivation and defined regulation). Similarly, a study conducted with 8th-grade students in Germany found no significant gender differences in terms of intrinsic motivation and self-regulation (Raufelder, Scherber, & Wood, 2016). SDL is a learning context in which students set their own learning goals and develop individual paths to achieve these goals (Brockett & Hiemstra, 1991). Therefore, SD-Learners know where and how to locate the necessary resources while developing individual paths (Moore, 1986). This type of learning can potentially reduce gender differences because it is based on the students' own interests. Students build on their prior knowledge to create individualized learning paths (Schweder & Raufelder, 2021). Considering that the Covid-19 period was the period when awareness of the importance of SDL, which is based on individualized learning, was at its highest (Tlili, Burgos, Olivier, & Huang, 2022), it can be thought that gender ineffectiveness is an expected situation.

Among the affective variables examined in the study, 21st-century math self-efficacy emerged as the variable that most strongly increased the likelihood of students having above-average SDL self-efficacy. In addition, the effort/perseverance variable in mathematics is another important and powerful variable that significantly increases the likelihood of having above-average SDL self-efficacy. Furthermore, the affective variable that significantly increases the likelihood of having SDL self-efficacy is mathematical self-efficacy. Therefore, both mathematical self-efficacy variables predict SDL self-efficacy. PISA assesses 21st-century mathematical self-efficacy, which involves questioning students' academic beliefs about contemporary mathematical skills. This scope encompasses skills such as analyzing and interpreting data in mathematics, relating mathematical concepts to daily life, applying statistical analysis in uncertainty and data-driven decision-making processes, critically and analytically examining mathematical models, working with computerized mathematical systems, and solving real-world problems. One of the most important roles of perceived self-efficacy is that it affects an individual's capacity to effectively use their knowledge and skills. According to the social cognitive learning theory, individuals with high self-efficacy set challenging goals for themselves and tend to exert more effort when faced with difficulties (Bandura, 1993). Therefore, these individuals have a firmer belief in their own abilities to organize and carry out an action to achieve specific goals. Research findings also support these conclusions in the literature. For example, the study by Miles and Vela (2022) revealed that mathematical self-efficacy contributes to students' behavior of seeking help when needed, which is an important component of self-efficacy, and that self-efficacy has a significant effect on students' setting goals for themselves and selecting the necessary strategies to achieve these goals (Saks, 2024). Similarly, Sadi and Uyar (2013) found that high self-efficacy is an important dynamic for completing a task when students encounter difficulties and that higher self-efficacy may be directly related to self-regulated learning strategies, metacognitive learning strategies, learning environment management strategies, and effort regulation strategies. According to these findings, mathematical self-efficacy remains an important variable in students' learning management skills, as stated in the literature. Especially in recent years, mathematics problems in national and international exams have been presented as non-routine problems (Lindquist, Philpot, Mullis, & Cotter, 2017) that students are unfamiliar with, that do not have a memorized solution algorithm, and that require reorganizing thoughts and using reasoning skills to reach a solution. Therefore, when we evaluate PISA-context math problems in this way, it is important for students to manage their math learning processes.

Effort also emerged as a meaningful correlate of self-efficacy in our analyses. Conceptually, effort aligns with broader volitional control and self-regulatory processes that translate intentions into sustained action (Artelt, Baumert, Julius-McElvany, & Peschar, 2003). Within the learning context, such volitional strategies support persistence, promote continuity on tasks, and facilitate the pursuit of long-term learning goals (Brunstein & Heckhausen, 2018). Prior work further suggests that students who invest greater effort tend to maintain motivation even after setbacks or earlier failure experiences (Schweder & Raufelder, 2021). In mathematics in particular, effort has been linked to students' competence-related beliefs, consistent with the idea that perceived capability and persistence may reinforce one another (Chouinard & Roy, 2008).

Among the affective variables, it is a significant finding that math anxiety and math motivation also have a negative effect. Increased anxiety reduces the likelihood of students having above-average self-efficacy in math. Similarly, it has been concluded that as students' math motivation increases, the likelihood of having above-average self-efficacy in math decreases. Anxiety and stress experienced in mathematical tasks have negative effects on mathematics learning (Richardson & Suinn, 1972). High anxiety is associated with negative attitudes toward mathematics, reduced interest in mathematics, lower task values, and low levels of self-concept and self-confidence (Dowker, Sarkar, & Looi, 2016; Gabriel, Buckley, & Barthakur, 2020). Considering that anxiety experienced in mathematics classes is more pronounced at these grade levels, research findings should take the necessary measures to reduce the mathematical anxiety experienced by students. When we consider the meta-analysis studies by Zhang, Zhao, and Kong (2019), it has been found that high school students have more mathematical anxiety than middle school students. This is understandable because high school mathematics curricula are more challenging and require greater cognitive engagement. Therefore, the increase in students' mathematical anxiety should be taken into account, and it should not be forgotten that supportive practices are necessary to control this variable that affects their mathematical performance.

Although the negative prediction of above-average mathematics motivation on self-efficacy may seem surprising at first glance, it presents a consistent picture with motivation and anxiety studies in the Turkish context. Niehues, Kisbu-Sakarya, and Selcuk (2020) have shown that students in Türkiye report higher motivation in mathematics compared to many other countries. However, the increase in mathematics anxiety in PISA 2022 compared to previous years (OECD, 2023) suggests that motivation is often intertwined with pressure. Accordingly, relatively high motivation in a specific area may lower self-perceptions in other areas (Möller & Marsh, 2013). Therefore, students may position themselves as someone who focuses on being good at mathematics in particular, rather than as a competent learner. Furthermore, when we look at the items that make up the index related to motivation in mathematics in PISA 2022, we see that it involves prioritizing mathematics over Turkish and science rather than absolute motivation. In this case, students who are relatively highly motivated in mathematics may struggle to develop general self-efficacy in learning while focusing on this area.

An increase in the variable of finding mathematics easy, which is among the perceptual variables, reduces the likelihood of above-average self-efficacy in learning mathematics. In other words, as finding mathematics easy increases, the likelihood of the student having above-average self-efficacy in learning mathematics decreases. The expected level of education can be said to have a moderately positive effect. The finding emerging from the relationship between finding mathematics easy and self-efficacy in mathematics may be that one of the reasons students find mathematics easy is that they complete certain tasks with less effort. This also reduces the need to use strategies such as planning and monitoring the learning process. Bandura (1997) argues that a task's perceived difficulty is subjective and varies across individuals. These appraisals shape students' self-efficacy judgments and, consequently, the intensity of their efficacy beliefs. Accordingly, when forming self-efficacy beliefs, students attend to the task they face (Direction) and to how demanding they judge it to be (Level) (Street, Malmberg, & Stylianides, 2017). For example, in the studies by Street, Stylianides, and Malmberg (2022), the increase in mathematical self-efficacy was only associated with an increase in test performance on tasks perceived as "moderate" and "difficult." This shows that easy tasks do not provide sufficient feedback for self-efficacy development. Therefore, it is important for teachers to use activities with gradually increasing difficulty levels in mathematics lessons, rather than only presenting easy tasks; to support students in recognizing the difficulty levels of these tasks themselves; and to create learning environments where they can provide constructive feedback, especially on difficult tasks. These environments can also offer opportunities for students to strengthen self-management skills in learning. Another situation considered in interpreting this finding of the research is that students may have low goals for the course. If we consider this situation within the framework of achievement goal theory (Elliot & McGregor, 2001), according to this theory, the reasons why students learn a course are important. These reasons may include sub-reasons such as being better than others, demonstrating success to others (Performance goal orientation), or professionalization through in-depth learning (Mastery goal orientation). These reasons also have an important effect on students' effort, strategy use, and self-efficacy formation. If students' goals related to the course are low, their mastery goals in learning may also be weak. Consequently, this situation does not provide the motivation and effort necessary for the development of students' self-efficacy skills and self-efficacy. Research findings in the literature also reveal this interaction. For example, Huang (2016) meta-analysis study revealed a strong correlation between mastery goals and self-efficacy. Similarly, Lee, Bong, and Kim (2021) found that students with mastery goals in learning were more successful in self-control, which is a sub-skill of self-efficacy. Although the other variable considered in the study, expected educational level, represents a general expectation, mathematics is an important subject for students in planning their future educational processes. Therefore, general expectations are shaped by the expectations that arise in the classroom. The findings of the study in this context are mutually supportive.

Findings related to the student–teacher relationship yielded several notable patterns. A higher-quality teacher–student relationship was associated with greater odds of students reporting above-average self-efficacy. Prior research indicates that strong teacher–student bonds are linked to mathematics achievement (Hughes & Kwok, 2007), and building positive relationships is widely viewed as central to creating supportive learning environments (Appiah, Korkor, Arthur, & Obeng, 2022). Studies in the literature have also produced findings that support this interpretation. For example, Dan and Bai (2025) found that quality teacher-student relationships positively affect students' self-regulated learning skills. Similarly, Zee and de Bree (2017) showed that such relationships directly affect students' task orientations and levels of metacognitive skill use in mathematics classes. On the other hand, contrary to quality relationships, findings also exist showing that conflictual teacher-student relationships are associated with effort-demanding components such as control, attention, and discipline, which negatively affect students' self-regulation processes (Berry, 2012; Hamre & Pianta, 2001; Zee & de Bree, 2017).

One of the most noteworthy findings of the study is that teacher support alone is not a statistically significant predictor of SDL self-efficacy. In addition, an important interaction has come to the fore in the study. The findings indicate that the effect of math anxiety on SDL self-efficacy varies depending on the level of teacher support. When teacher support is low, the effect of anxiety on SDL self-efficacy is insignificant, whereas when teacher support is high, the effect of anxiety becomes distinctly negative. This indicates that as teacher support increases, the negative effect of math anxiety on SDL self-efficacy intensifies. Therefore, the findings suggest that teacher support does not act as a protective factor in all circumstances; on the contrary, it may make the effect of anxiety more apparent in certain contexts. The literature has found that supportive teaching environments are positively related to overall performance on learning-related tasks (Stroet, Opdenakker, & Minnaert, 2013). However, in some studies, this relationship is either weak or non-existent (Opdenakker, 2022; Skinner & Belmont, 1993). The current finding contributes to this inconsistent literature and shows that the effect of teacher support may not be linear and unidirectional. In particular, the nature of the support, the student's perception, and the cultural context may determine the direction of this relationship. According to Deci and Ryan (1985) and Deci and Ryan (2000), Self-Determination Theory, one of the most fundamental needs of human motivation is the need for autonomy. Students' sense of control over their own learning processes, ability to make choices, and use of their own initiative are critical for the development of intrinsic motivation and self-determination skills. Studies conducted in the Turkish context have shown that extrinsic motivation has a stronger effect on academic achievement than intrinsic motivation (Eker & Yildizli, 2025). This indicates that controlled motivation structures are dominant in the education system. When the items under the teacher support variable in PISA are examined, it is seen that this support is instructional support. Autonomy support (Wang et al., 2024), an important component of teacher support, is not addressed within the framework of the measured variable. Considering that instructional support in Türkiye is mostly provided in a controlling manner, the current findings reflect the Turkish educational culture. For example, Durmuşçelebi and Çetinkaya (2018) found in their study with teachers in Türkiye that teachers of numerical subjects, such as mathematics, had the lowest level of belief in the necessity of behaviors related to learner autonomy. Özkal and Demirkol (2014) study also revealed that mathematics teachers exhibited the lowest level of learner autonomy support behaviors compared to teachers of other subjects. Therefore, the controlling nature of mathematics teachers' support may cause students to become more dependent on the teacher in the learning process. In this context, it can be argued that for students with high mathematics anxiety, increased teacher support may heighten their sensitivity to performance demands and foster greater reliance on external guidance. This, in turn, undermines the self-regulatory beliefs that underpin self-directed learning. Therefore, for teacher support to be genuinely effective for anxious students, it must extend beyond instructional guidance to encompass autonomy-supportive practices that foster students' sense of agency and ownership over their learning processes.

Regarding family-related variables, it has been found that family support is the strongest positive variable for SDL, while general family support has a moderately positive effect. This finding is particularly important for the post-COVID-19 period. This is because various studies (Demir & Yildizli, 2022; Thomson et al., 2021) show that family support has become more visible in student learning after this process and that this support will now continue even more. Recent studies have also shown that family support is important in students' SDL orientations (Yanxia, Shaomin, Jiheng, Ruimei, & Hong, 2025) in using self-regulated learning strategies (Kadhiravan, 2011) and in influencing their academic resilience (Cheraghian, Moradian, & Nouri, 2023; Suud, Agilkaya-Sahin, Na'Imah, Azhar, & Kibtiyah, 2024) and developing autonomy (Thomas, Muls, De Backer, & Lombaerts, 2021). In Türkiye, high school years are crucial, as they involve national exams. Mathematics is one of the most dreaded subjects for both adolescents (Horzum & Yildirim, 2016; Koçak & Bilecik, 2019) and parents (Bozkurt & Dülger, 2021). Despite an exam-focused and competitive education system, parent-child communication during high school years is less supportive and more conflictual than in previous years (Furman & Buhrmester, 1992). At the same time, adolescents in this age group are in a developmental period where they are very sensitive to social comparison processes, attach great importance to peer networks, and are overly concerned with their social profiles (Gonida, Kiosseoglou, & Voulala, 2007). Therefore, while family relationships become more complex on the one hand, the family's involvement in the student's educational life and the support provided in this context are important, according to research findings. For this reason, the continuity and quality of family support in supporting students' academic and psychological development, especially during high school, should be seen as an indispensable component of the learning process.

Other findings emerging from the research concern the effects of learning environments on students' self-efficacy in learning. Students' exposure to 21st-century skills in the classroom has a positive effect on self-efficacy in learning. However, it should not be forgotten that this effect is weak. Furthermore, problems experienced in the classroom related to self-determination have a weak negative effect on self-determination self-efficacy. According to self-determination theory (Deci & Ryan, 1985), learning environments are important because they meet students' basic needs related to the learning process. For students, these environments play a critical role in developing skills such as having positive feelings about learning, using effective learning strategies, and being autonomous in learning (Ryan & Deci, 2020; Schweder & Raufelder, 2021). Studies have also shown a positive relationship between 21st-century skills and SDL skills (Karataş & Arpacı, 2021) and that a learning environment equipped with 21st-century skills increases self-direction compared to a traditional learning environment (Fahnoe & Mishra, 2013). The 21st-century skills in mathematics within the scope of PISA reflect the importance given to 21st-century skills, problem-based learning, and mathematical literacy in mathematics education. This is because students experience a lack of confidence in understanding math problems, recognizing alternative ways to solve them, and calculating or verifying their solutions (Desoete, Roeyers, & De Clercq, 2003). This situation shows that students' difficulties in problem solving may not always stem from a lack of mathematical knowledge but rather from their inability to effectively apply their knowledge due to a lack of the metacognitive skills necessary to control, monitor, and reflect on the solution process (Tzohar-Rozen & Kramarski, 2014). In this context, 21st-century skills, which also address problem-solving skills and encompass skills such as critical thinking, are also important.

5. CONCLUSION AND RECOMMENDATIONS

Based on PISA 2022 data, this study aimed to identify the factors influencing the likelihood of 15-year-old students having above-average SDL self-efficacy. The general findings reveal that the strongest factors supporting this self-efficacy are students' high academic beliefs and perseverance. Specifically, 21st-century mathematics self-efficacy, which encompasses students' beliefs about their contemporary mathematical skills (analyzing and interpreting data, solving real-world problems, and a critical perspective), was identified as the variable that most strongly increased the likelihood of above-average SDL self-efficacy. This situation, combined with qualified family support for SDL, which emerged as the strongest positive variable in mathematics effort/perseverance and family-related variables, forms the fundamental driving forces that increase self-efficacy. Furthermore, the biggest obstacles to mathematics self-efficacy are increased mathematics anxiety and the perception of mathematics as easy; this perception is negatively associated with lower mathematical self-efficacy development by reducing the need for students to use strategies such as planning and monitoring the learning process. Additionally, while the quality of the teacher-student relationship has a positive effect, teacher support alone is not a statistically significant predictor. The interaction analysis revealed that higher levels of teacher support amplify, rather than buffer, the negative association between math anxiety and SDL self-efficacy. This counterintuitive finding likely reflects the predominantly instructional and directive nature of teacher support as measured in PISA, which may increase performance pressure for anxious students rather than fostering the autonomy necessary for self-directed learning. The fact that gender is not a significant variable in SDL self-efficacy can be explained by the fact that SDL starts from students' own interests and is based on individualized learning. In conclusion, students' strong belief in their learning abilities and external support play a critical role in the ability of 15-year-old adolescents to effectively manage their learning processes.

The study reached an interesting conclusion that as students' motivation in mathematics increases, the likelihood of them having above-average self-efficacy in SDL decreases. Future research should thoroughly examine the underlying reasons for this unexpected relationship. For example, it could be investigated whether high motivation stems from exam-focused external reasons or whether motivation leads to focusing solely on rote learning rather than SDL strategies. This study also found that an increase in the variable of finding mathematics easy reduced self-efficacy in mathematics. In this context, it may be necessary to classify students who find mathematics easy as successful or unsuccessful based on their academic achievement in mathematics, and then conduct in-depth research on why students in both groups find mathematics easy. Furthermore, the study revealed a complex interaction finding that when teacher support is low, increasing math anxiety increases students' self-efficacy in mathematics, while when teacher support is high, it decreases it. Future research should include qualitative and in-depth studies to explain the underlying reasons for this pattern. Items related to autonomy support should be addressed under teacher support in future PISA measurements.

Several limitations should be noted. First, the dichotomization of the continuous SDL self-efficacy index, although theoretically and practically justified (see Section 2.2.1), inevitably involves some loss of information. Future studies should replicate these findings using continuous outcome modeling (e.g., linear regression or ordinal approaches) to assess the robustness of the observed patterns. Second, the cross-sectional design precludes causal inferences; all findings should be interpreted as associations rather than causal effects. Third, while the design-based BRR approach adequately corrects for clustering, future research may employ multilevel logistic regression to examine potential cross-level interactions between student- and school-level factors. Fourth, the teacher support measure in PISA captures only instructional support; future assessments should include items measuring autonomy support to evaluate the role of teacher support more comprehensively in students' self-directed learning development.

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