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Research Article

Investigation of the Variables Affecting Science Literacy in PISA 2003–2018 Applications at School and Student Levels

PISA 2003–2018 Uygulamalarında Fen Okuryazarlığını Etkileyen Değişkenlerin Okul ve Öğrenci Düzeyinde İncelenmesi

Bilge Acar*, Selahattin Gelbal**

* Ministry of National Education, Ankara, Türkiye. E-mail: bilgeacar05@yahoo.com
Millî Eğitim Bakanlığı, Ankara, Türkiye. E-posta: bilgeacar05@yahoo.com

** Hacettepe University, Faculty of Education, Ankara, Türkiye. E-mail: gelbal@hacettepe.edu.tr
Hacettepe Üniversitesi, Eğitim Fakültesi, Ankara, Türkiye. E-posta: gelbal@hacettepe.edu.tr

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Abstract

Purpose: *The purpose of this study is to explore the determinants of science literacy achievement among Turkish students across the Programme for International Student Assessment 2003-2018 cycles. The research investigates which student- and school-level variables contribute to science literacy performance and whether these relationships endure successive PISA cycles.* ***Method:*** *A relational design was adopted to assess how student- and school-based predictors are linked to science literacy, using analytical procedures grounded in multilevel and multivariate modeling. Multilevel Structural Equation Modeling was employed, with plausible values and sampling weights taken into account.* ***Findings:*** *The findings reveal differences in science literacy scores among schools across all PISA cycles. Predictors of science literacy varied by assessment year: In 2003, parental occupational status at the student level and the student–teacher ratio at the school level were the strongest variables. In 2006, parental occupational status and home possessions at the student level, and school location at the school level were found to be significant. In 2009, home resources at the student level and both school region and the student–teacher ratio at the school level were influential. In 2012, program type at the student level and the student–teacher ratio at the school level stood out. In 2015, significant predictors included parental occupational status for students and school region as well as school size for schools. In 2018, student-level parental occupational status and school region at the school level remained the key determinants.* ***Conclusion:*** *This research is significant as it covers six PISA cycles, tracks changes in science literacy, and identifies influential factors.*

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Öz

Amaç: *Bu araştırmanın amacı, PISA 2003-2018 uygulamalarına katılan Türkiye örneklemindeki öğrencilerin fen okuryazarlığı başarısını yordayan değişkenleri belirlemektir. Çalışmada, öğrenci ve okul düzeyinde hangi değişkenlerin fen okuryazarlığı performansını anlamlı biçimde açıkladığı ve bu ilişkilerin PISA döngüleri boyunca hangi ölçüde tutarlı biçimde devam ettiği incelenmiştir.* ***Yöntem:*** *Araştırmada ilişkisel tarama deseni kullanılmış ve öğrenci ile okul temelli değişkenlerin fen okuryazarlığı üzerindeki etkileri çok düzeyli ve çok değişkenli analizler aracılığıyla değerlendirilmiştir. Analizler Çok Düzeyli Yapısal Eşitlik Modellemesi ile gerçekleştirilmiş; olası değerler ve örneklem ağırlıkları dikkate alınmıştır.* ***Bulgular:*** *Bulgular, tüm PISA döngülerinde öğrencilerin fen okuryazarlığı puanlarının okullar arasında farklılaştığını göstermektedir. Ayrıca, yordayıcı değişkenler yıllara göre değişiklik göstermiştir: PISA 2003'te öğrenci düzeyinde ebeveynlerin mesleki statüsü, okul düzeyinde öğrenci–öğretmen oranı; 2006'da öğrenci düzeyinde ebeveynlerin mesleki statüsü ve ev kaynakları, okul düzeyinde okulun bulunduğu bölge; 2009'da öğrenci düzeyinde ev kaynakları, okul düzeyinde okulun bulunduğu bölge ve öğrenci–öğretmen oranı; 2012'de öğrenci düzeyinde program türü, okul düzeyinde öğrenci–öğretmen oranı; 2015'te öğrenci düzeyinde ebeveynlerin mesleki statüsü, okul düzeyinde okulun bulunduğu bölge ve okul büyüklüğü; 2018'de ise öğrenci düzeyinde ebeveynlerin mesleki statüsü ve okul düzeyinde okulun bulunduğu bölge istatistiksel olarak anlamlı bulunan değişkenler olmuştur.* ***Sonuç:*** *Araştırma, altı PISA döngüsünü kapsaması, fen okuryazarlığı performansındaki değişimleri izlemesi ve başarıya etki eden faktörleri ortaya koyması bakımından önem taşımaktadır.*

Introduction

Countries need to conduct assessments at national and international levels to evaluate their education systems. International large-scale assessments provide countries with the chance to review the strong and weak aspects of their education systems, while also allowing them to benchmark their performance against other participating nations (Aydın, 2017; Goldstein, 2004; Lenkeit, 2012). Ritzen (2013) emphasizes that large-scale assessments are a powerful tool for countries to make decisions regarding their education systems. Through such assessments, it becomes possible to monitor changes in student achievement over time, identify the factors affecting student performance, and determine the strengths and weaknesses of national education systems.

Among international large-scale assessments, the Programme for International Student Assessment (PISA) is recognized as a major study, carried out under the coordination of the Organisation for Economic Co-operation and Development (OECD). Today, the PISA assessment has expanded beyond OECD member countries and reached a global scale by including more than 90 countries (OECD, 2019c). According to the Ministry of National Education (MoNE, 2019), the central objective of PISA is to evaluate how well 15-year-old students can apply what they have learned at school both knowledge and skills when facing everyday situations. After the age of 15, some students continue formal education, some pursue vocational training, while others join the workforce. Before this turning point, PISA provides data on how well students are prepared for these systems (Lietz et al., 2017). Through PISA, the competencies of 15-year-old students are examined in three key areas: science literacy, mathematical literacy, and reading.

PISA is designed to assess how effectively students can apply the knowledge and skills they have learned in school to situations encountered in everyday life, using both cognitive tests and background questionnaires (OECD, 2013). While the cognitive tests aim to measure students' literacy skills, the questionnaires are designed to collect data on several factors such as students, teachers, parents, and school characteristics. In the PISA assessment, questionnaires hold critical importance as they provide insight into factors influencing student performance (OECD, 2016). Data collected through student and school questionnaires make it possible to examine how students' science literacy outcomes are associated with family and school-related factors (Thien, 2016). According to OECD (2016), students answer a background questionnaire that aims to capture details about their individual characteristics, family environment, educational setting, and experiences of learning. In PISA, the school survey is filled out by principals and supplies data on resources, organizational structure, student and teacher characteristics, instructional practices, curriculum, evaluation processes, school climate, and educational policies. These data allow comparisons between schools and help identify school level factors that influence student achievement (MoNE, 2015). Therefore, the information obtained from the school questionnaire provides insights into the contribution of school facilities to students' performance at both national and international levels and supports the analysis of similarities and differences among schools.

The PISA assessment is conducted in three-year cycles, with the 2006 and 2015 cycles specifically emphasizing science literacy as the primary domain. This systematic structure enables researchers to track shifts in student performance and analyze how relationships between student traits, family background, and school-level factors evolve over time (Pokropek et al., 2017). By monitoring these changes, participating countries can evaluate the effectiveness of educational reforms and align their national outcomes with international standards (OECD, 2019a).

In this study, science literacy is defined by PISA as students' competence to interact with scientific subjects and consider scientific events (OECD, 2019a). In assessing science literacy, PISA evaluates both students' scientific understanding and their ability to apply it in practical, real-world contexts (OECD, 2016). A scientifically literate individual cares about science-related questions and readily participates in dialogues addressing scientific and technological issues. Science literacy encompasses skills including the explanation of natural events and facts through science, the ability to plan and assess scientific inquiries, and the interpretation of evidence by applying scientific reasoning (MoNE, 2015). The concept of science literacy also encompasses affective characteristics. Learners' orientations and approaches to science can affect how interested and motivated they are, as well as their long-term participation in science-related learning (OECD, 2016).

Accordingly, science literacy as assessed in PISA represents a broader construct than the school science curriculum (OECD, 2019a). The science literacy scores of Turkish students over time yield significant information about their academic performance.

Regarding the science literacy scores of Turkish students over time, it is evident that Türkiye ranked 34th among 40 participating countries in the 2003 PISA assessment, with a score of 434, falling well below the international average (496) and the OECD average (500). In 2006, the first cycle where science was the primary domain, Türkiye ranked 47th out of 57 countries with a score of 424. In the 2009 cycle, the rank was 42nd with a score of 454, and in 2012, Türkiye ranked 43rd with a score of 463, still lagging behind the OECD average of 501. In the 2015 assessment, which again focused on science as the primary domain, the score dropped to 425, ranking Türkiye 54th among 72 countries. However, in the 2018 cycle, Türkiye achieved a score of 468, ranking 39th and surpassing the international average for the first time, although remaining below the OECD average of 489.

When examining the trend of science literacy results, Türkiye has not surpassed the mean score of OECD countries in any PISA cycle in which it has taken part. However, the 2018 cycle marked the first time Türkiye's science literacy score surpassed the overall international average. Another noteworthy trend is the steady improvement in science literacy scores through the 2012 cycle, followed by a significant decline in 2015. Nonetheless, the 2018 cycle showed a rebound in performance.

To formulate effective educational policies, identifying the multifaceted determinants of student achievement is essential. Rather than viewing performance in isolation, research must account for the complex interplay between student, family, and school-level variables. In the Turkish context, a robust body of literature within the PISA framework consistently highlights that student-level characteristics—most notably socioeconomic status (SES), home educational resources, and cultural capital—serve as fundamental predictors of science literacy (Yitik, 2019; Çeçen, 2015; Gülleroğlu et al., 2014). The enduring influence of family background is further evidenced by the significant association between parental education/occupational status and student performance across multiple PISA cycles (Buldu & Olgan, 2018; Kartal et al., 2017; Dinçer & Kolaşin, 2009). While gender remains a relevant factor, its impact appears to fluctuate depending on the specific assessment year (Aksu et al., 2017; Kartal et al., 2017).

However, student achievement is not merely a product of individual background; it is deeply embedded within institutional contexts. School-level characteristics, such as school size, student–teacher ratios, and regional location, are associated with the learning environment (Özkan, 2015; Acar, 2012). Theoretically, the importance of these institutional factors is underscored by the high degree of between-school variance observed in Türkiye. For instance, Aksu et al. (2017) noted that nearly 63% of the variation in outcomes can be attributed to differences between schools, a finding supported by Çelebi's (2010) cross-country comparisons which suggest that school-level differences are primary contributors to science literacy gaps.

Despite the breadth of these findings, existing research often remains fragmented, focusing on isolated cycles and failing to capture long-term trends (Erbaş, 2005; Gürsakal, 2012; Özer, 2009). There is, therefore, a critical need for a comparative cross-sectional perspective that examines how these predictors evolve across successive cycles. PISA's consistent assessment framework and background surveys provide the necessary data to understand these contextual shifts through repeated cross-sectional analyses. From a methodological standpoint, the hierarchical nature of PISA data—where students are nested within schools—demands analytical approaches that respect this structure (Heck & Thomas, 2020; Hox, 2010; Kaplan & Elliot, 1997). Since students within a school share a common environment, their scores are not independent (Stevens, 2009); ignoring this dependency in single-level analyses can lead to significantly biased results.

The theoretical necessity of employing multilevel modeling is best illustrated by Borman and Dowling (2010). Their comparison revealed that while school-level factors accounted for 40% of the achievement variance in a multilevel model, this figure was underestimated at only 18% in a single-level model. Such evidence confirms that multilevel models are more appropriate for capturing the true impact of institutional contexts (Tabachnick & Fidell, 2014). By utilizing Multilevel Structural Equation Modeling (MSEM), this research aims to provide a more accurate and simultaneous estimation of individual and group-level interactions, thereby offering a more nuanced understanding of the determinants of science literacy in Türkiye (Akgenç, 2018; Şen, 2020).

The selection of variables for this study was strategically guided by the necessity for both theoretical relevance and analytical consistency. The indicators were primarily identified based on the PISA conceptual framework and previous research, which highlight these specific student and school factors as the most significant predictors of science literacy. To ensure a reliable comparison across the six PISA cycles from 2003 to 2018, the analysis was limited to variables that were measured in the same way throughout the entire 15-year period. This deliberate approach ensures that the trends observed over time are based on identical indicators, allowing for a valid evaluation of how the relationship between these factors and science literacy has evolved. By focusing on these stable indicators, the study aims to determine whether the influence of family background and school resources on student performance has remained constant or changed in response to Türkiye's evolving educational landscape.

The purpose of this research is to examine how a set of student-related factors (e.g., gender, program type, home resources, parental occupation, and parental education) and school-related characteristics (such as school location, school size, and student–teacher ratio) contribute to explaining science literacy in Türkiye, using PISA data collected between 2003 and 2018. Furthermore, the study investigates the stability of these predictors across successive PISA cycles. By tracking shifts in science literacy achievement and identifying consistently influential factors, this research aims to provide significant insights that enrich the existing scholarly work. Notably, Özdemir (2016) highlighted a critical gap in the Turkish literature, observing that many studies lack essential information regarding sampling weights and plausible values, and often fail to employ multilevel models suitable for the hierarchical structure of PISA data. Consequently, the application of MSEM in large-scale assessments in Türkiye remains limited. By integrating MSEM while rigorously accounting for sampling weights and plausible values, this study serves as a methodological guide for researchers working with international large-scale assessment data. In accordance with these objectives, the primary research question guiding this study is:

What is the multilevel structural relationship between student and school level variables and science literacy achievement among students in the Turkish sample of the PISA 2003, 2006, 2009, 2012, 2015, and 2018 cycles? The sub-research questions are as follows:

1. Are there statistically significant differences in science literacy achievement among the schools that participated in the PISA 2003, 2006, 2009, 2012, 2015, and 2018 Türkiye assessments?

2. Which student-level variables (gender, program type, home resources, parental occupation, and parental education) and school-level factors (school location, school size, and student–teacher ratio) significantly predict students' science literacy scores in the PISA 2003–2018 Türkiye assessments?

Methodology

Research Design

This study investigated student- and school-level factors associated with science literacy performance across the PISA cycles of 2003, 2006, 2009, 2012, 2015, and 2018. Since the research aimed to identify both the existence and the magnitude of relationships among these variables, it was designed in accordance with the relational survey model (Fraenkel et al., 2012).

Population and Sample

To ensure valid cross-national comparisons of educational performance, PISA defines its target population based on age rather than grade level (OECD, 2019a). Within PISA, eligibility is limited to students who are at least 15 years and 3 months old but younger than 16 years and 2 months on the test date, provided they are enrolled in grade 7 or higher in any educational institution, independent of school category. The sample for each PISA cycle consists of students selected from the target population through a stratified sampling method. At the initial phase, a group of schools is chosen, and at the following phase, students are drawn randomly from those schools through a simple random procedure (OECD, 2016). Table 1 summarizes how many schools and students took part in the Turkish samples of the PISA assessments conducted in 2003, 2006, 2009, 2012, 2015, and 2018.

Table 1: *Number of Schools and Students in the Turkish Sample in PISA Assessments*

PISA Cycle	2003	2006	2009	2012	2015	2018
Number of schools	126	155	167	160	185	180
Number of students	3302	4390	4313	3980	5092	6567

Data Collection

Data was retrieved via the international PISA database provided by OECD (www.pisa.oecd.org). To identify the variables influencing Turkish students' science literacy performance, items from the student and school surveys completed by learners and school principals within the PISA assessment were utilized. The PISA assessment includes a variety of item formats, such as open ended, short answer, and multiple-choice questions.

Cognitive scores related to students' science literacy are estimated as plausible values, which are known as possible values for student performance. The purpose of PISA is not centered on producing individual-level valid and reliable scores, but on identifying the achievement patterns of populations and subgroups (Monseur & Adams, 2009). In this context, PISA employs a rotated test design (Rutkowski et al., 2010). Since students do not answer all the questions in this design, the testing burden on individuals is reduced, while all questions are answered at the group level. For these reasons, test results in the PISA assessment are reported as plausible values (Arıkan et al., 2020; OECD, 2019a). Plausible values are generated by randomly sampling from the score distribution that reflects students' response patterns, and these values are then assigned to individuals (OECD, 2017). Across PISA 2003, 2006, 2009, and 2012, only five plausible values were estimated, whereas the 2015 and 2018 cycles employed ten plausible values.

In preparing the datasets for analysis, the first step involved identifying the constructs and associated items that were common across all six PISA cycles. In the second step, the relevant literature was examined to identify further student and school level variables affecting academic performance. As a result of this step, factors classified as Level 1 (learner-related) and Level 2 (school-related) were selected for the study. The Level 1 variables consist of science literacy cognitive scores and individual student characteristics. Level 2 variables were derived from the school questionnaire. Variables at Level 2 came from the school survey, while Table 2 provides an overview of the student and school variables incorporated into the analysis.

Table 2: *Indicators Related to Students and Schools Utilized in the Analysis*

Level	Variable	Definition
Student level	GENDER	Gender
	PROGN	Program Type
	HOMEPOS	Home Possessions
	HISEI	Highest Parental Occupational Status
	PARED	Highest Parental Education Level (by Year)
School-level	SCHLOCATION	School Location
	SCHSIZE	School Size
	STRATIO	Student–Teacher Ratio

Data Analysis

The validity of the analyses depends on the fulfillment of the underlying assumptions. Accordingly, prior to the main analysis, the dataset was examined for missing data, outliers, and sample size adequacy, and necessary corrections were made. Subsequently, assumptions required for Multilevel Structural Equation Modeling (MSEM), including multivariate normality and multicollinearity, were rigorously assessed.

Missing Data and Outliers

To ensure the accuracy of the results, the dataset was first screened for missing values. Given the large sample size of the PISA dataset and the low proportion of missingness, listwise deletion was preferred (Cheema, 2012). In this context, cases with missing values at both the student and school levels were excluded to proceed with a complete dataset.

To identify univariate outliers, all variables were transformed into z-scores. Following the recommendation that outlier thresholds can be expanded in large-scale samples (Mertler & Reinhart, 2005), z-scores falling outside the ±4 threshold were considered outliers and excluded. To identify multivariate outliers, Mahalanobis distance was employed. Cases with a statistically significant Mahalanobis distance at the $p < .001$ level were identified as multivariate outliers and removed from the dataset (Tabachnick & Fidell, 2014).

Multivariate Normality and Multicollinearity

Skewness and kurtosis coefficients for the continuous independent variables were found to be within the ±2 range, satisfying the criteria for univariate normality (Kline, 2016). While linearity was largely maintained as indicated by Q-Q plots, scatterplot matrices revealed that some distributions did not perfectly approximate an elliptical shape. To mitigate the impact of these partial violations of multivariate normality, the Robust Maximum Likelihood (MLR) estimation method was employed in Mplus 7, as it provides standard errors and fit statistics that are robust to non-normality (Muthén & Muthén, 1998–2012). Multicollinearity was ruled out as Variance Inflation Factor (VIF) values were consistently below 10, tolerance values were above .10, and correlation coefficients did not exceed the .90 threshold (Kline, 2016).

Model Structure and Variables

A two-level MSEM was specified to account for the nested structure of the PISA data, where students (Level 1) are nested within schools (Level 2). The model was constructed as a random intercept model to capture between-school differences in achievement. At the within-level (student level), individual predictors including gender (gender was coded as 0 = female, 1 = male), program type, home possessions, parental occupation, and parental education were treated as observed variables. At the between-level (school level), school-level predictors such as school location (coded as an ordered numeric variable ranging from 1 = village to 5 = large city), school size, and student–teacher ratio were included to explain the variance in the random intercepts. Within this framework, science literacy was treated as an observed dependent variable at the within-level, while it was modeled as a latent random intercept at the between-level to represent between-school variance.

Sample Size and Analysis Procedure

Sample sizes at both the within-group level (minimum 200; Heck & Thomas, 2015) and between-group level (minimum 30; Stapleton, 2013) significantly exceeded the recommended thresholds across all PISA cycles, ensuring sufficient statistical power. Following the assessment of assumptions, student and school files for the 2003–2018 cycles were merged. To account for the rotated test design, science literacy was incorporated using Plausible Values (PVs). Accordingly, five PV files for each cycle prior to 2015 and ten PV files for the 2015 and 2018 cycles were analyzed simultaneously in Mplus 7 using the TYPE = IMPUTATION command. To prevent potential biases arising from the complex sampling design and to ensure the representativeness of the findings, the school-level sampling weight (W_SCHGRNRABWT) was incorporated into all models.

Research Ethics

Data employed in this research was retrieved via the OECD PISA online database (www.pisa.oecd.org). Since the datasets analyzed in the research do not contain any personal information regarding students or school administrators, there are no ethical concerns associated with the research. Therefore, ethical approval was not required.

Findings

This part of the study reports the results of the data analysis, organized according to the order of the research questions.

Findings Related to Research Question 1

The study examined whether science literacy outcomes varied meaningfully across schools in the Turkish samples of the PISA 2003–2018 cycles. To address the first research question, the Intraclass Correlation Coefficient (ICC) was calculated based on students' science literacy scores. The results are shown in Table 3.

Table 3: *Intraclass Correlation Coefficients for Science Literacy Performance in PISA Assessments*

PVSCIENCE	ICC	Student Level Difference	School Level Difference
2003	.64	36%	64%
2006	.57	43%	57%
2009	.70	30%	70%
2012	.65	35%	65%
2015	.58	42%	58%
2018	.58	42%	58%

According to Table 3, science literacy achievement showed intraclass correlation coefficients of .64 (2003), .57 (2006), .70 (2009), .65 (2012), and .58 for the 2015 and 2018 cycles. An ICC value greater than .05 indicates the necessity of using a Multilevel Structural Equation Modeling (MSEM) approach for analysis (Heck, 2020). Accordingly, the ICC values obtained in all PISA cycles 2003, 2006, 2009, 2012, 2015, and 2018 are suitable for analysis using the Multilevel Structural Equation Modeling approach.

As shown in Table 3, for the 2003 PISA round, 64% of the variability in science literacy scores can be traced to school-level differences, while the remaining 36% reflects individual-level variation among students in the same institution. In the 2006 cycle, 57%

of the variance is explained by school differences and 43% by within school (student level) differences. For the 2009 cycle, 70% of the variance stems from between school differences, and 30% from individual differences within schools. For PISA 2012, school-level factors accounted for 65% of the variability, with the other 35% linked to student-level factors. In the 2015 and 2018 assessments, 58% of the variation in science literacy was associated with disparities across schools, whereas 42% reflected differences among students within schools.

Across all six PISA cycles (2003, 2006, 2009, 2012, 2015, and 2018), a majority of the variation in science literacy achievement is explained by differences between schools. This finding suggests that science literacy performance cannot be explained solely by student level characteristics; rather, there are additional levels such as school-level factors that significantly predict science literacy outcomes.

Findings Related to Research Question 2

The study's second inquiry explored to what extent student characteristics such as gender, program type, household possessions, parents' job status, and parental education background and school characteristics namely location, institutional size, and the ratio of students to teachers—predicted students' science literacy scores in the Turkish samples of the PISA 2003–2018 assessments.

Analyses covering all PISA cycles revealed an RMSEA value of .000. This indicates that the model parameters show an excellent fit with the population covariance structure. Both CFI and TLI values were found to be 1.000, suggesting that the model exhibits perfect fit across all PISA cycles. The SRMR values, which separately indicate the model fit for the within-group (student) and between-group (school) levels, were found to be .001 at both levels. According to these values, the model displays high adequacy across both layers. Considering all model fit indices together, it can be concluded that the model exhibits an excellent fit for all PISA cycles analyzed.

This situation occurred because the measurement model, whose theoretical framework was previously established by PISA experts, was not included in the tested structural model; instead, the multilevel path model shown in the figure was tested. The saturated nature of path models and the fact that the degrees of freedom are zero (df=0) prevent the model from being tested in a traditional sense and cause the obtained values to be reported as perfect.

The evaluation of the model's fit with the data is not limited to fit indices. In addition, the estimated parameter values and their statistical significance must be examined. Accordingly, the parameter estimates of the variables were examined, covering variation at both the student and school levels. Standardized parameter estimates are useful for interpreting and comparing coefficients of variables measured on different metrics (Heck & Thomas, 2020). Table 4 presents the parameter estimates, significance values, and STDYX for the within-group and between-group variables in the PISA 2003 cycle.

Table 4. *Estimated Parameter Values for Within and Between Group Variables Predicting Science Literacy Performance in the PISA 2003 Assessment*

Variable	Estimate	Std. Error	Estimate / Std. Error	p value	STDYX
Gender	3.434	6.204	.554	.580	.026
Program Type	1.379	3.821	.361	.718	.048
Highest Parental Occupational Status	.547	.178	3.080	.002	.139
Highest Parental Education Level (by year)	-.328	.855	.383	.702	-.022
Home Possessions	7.944	4.355	1.824	.068	.127
School Location	20.626	10.735	1.921	.055	.276
School Size	.024	.019	1.273	.203	.183
Student–Teacher Ratio	-3.170	.907	- 3.494	.001	-.561

Since the variables are measured on different metrics, standardized parameter estimates, provided in the last column of Table 4, are used for comparison purposes instead of the unstandardized estimates. As shown in Table 4, student level, highest parental occupational status (γ = .139), and at the school-level, student–teacher ratio (γ = –.561), have statistically significant direct effects on the dependent variable ($p< .01$). Among all variables, the student–teacher ratio exhibits the strongest standardized path coefficient with science literacy scores. The effect of this variable is negative, indicating that as the student–teacher ratio increases, science literacy performance decreases. The specified model indicates that each unit rise in parental occupational status is associated with a 0.547 point gain in science literacy scores. On the other hand, when the student–teacher ratio rises by one unit, science literacy performance declines by about 3.170 points. Within the model, student–teacher ratio emerges as the strongest predictor of science literacy performance. Table 5 presents the parameter estimates, significance values, and standardized coefficients (STDYX) for the within group and between group variables in the PISA 2006 cycle.

Table 5: *Estimated Parameter Values for Within and Between Group Variables Predicting Science Literacy Performance in the PISA 2006 Assessment*

Variable	Estimate	Std. Error	Estimate / Std. Error	p value	STDYX
Gender	-2.395	5.349	-.448	.654	-.021
Program Type	-1.771	1.819	- .974	.330	-.098
Highest Parental Occupational Status	.426	.165	2.581	.009	.114
Highest Parental Education Level (by year)	-.242	.767	- .316	.752	-.015
Home Possessions	6.049	2.588	2.337	.0019	.132
School Location	35.808	8.050	4.448	.000	.638
School Size	-.024	.020	-1.225	.221	-.184
Student–Teacher Ratio	-1.047	1.056	-.992	.321	-.165

An examination of Table 5 indicates that at the student level, highest parental occupational status (γ = .114), and at the school level, school location (γ = .638), have statistically significant direct effects on science literacy performance ($p< .01$). Among all variables, school location has the highest standardized path coefficient with science literacy scores. Findings from the model suggest that a unit change in the highest parental occupational status results in a 0.426-point gain in science literacy, whereas a unit shift in school location yields a 35.808-point increase. Therefore, school location emerges as the strongest predictor of science literacy performance within the model. Table 6 presents the parameter estimates, significance values, and standardized coefficients (STDYX) for the within group and between group variables in the PISA 2009 assessment.

Table 6: *Estimated Parameter Values for Within and Between Group Variables Predicting Science Literacy Performance in the PISA 2009 Assessment*

Variable	Estimate	Std. Error	Estimate/ Std. Error	p value	STDYX
Gender	-2.749	2.755	- .998	.318	-.025
Program Type	3.888	2.131	1.825	.068	.271
Highest Parental Occupational Status	.189	.124	1.528	.126	.053
Highest Parental Education Level (by year)	.483	.560	.862	.389	.032
Home Possessions	4.949	1.375	3.600	.000	.133
School Location	20.825	7.644	2.724	.006	.413
School Size	-.039	.020	-1.972	.049	-.343
Student–Teacher Ratio	-3.270	1.108	- 2.951	.003	-.385

When Table 6 is examined, it is observed that at the student level, home possessions (γ = .133), and at the school level, school location (γ = .413) and student–teacher ratio (γ = –.385), have statistically significant direct effects on science literacy performance (p<.01). Among these variables, school location has the highest standardized path coefficient with science literacy scores. According to the specified model, a one unit increase in school location corresponds to a 20.825 point increase in science literacy performance; a one unit increase in student–teacher ratio corresponds to a 3.270 point decrease; and a one unit increase in home possessions corresponds to a 4.949 point increase in science literacy scores. Accordingly, school location is the strongest predictor of science literacy performance in the model. Table 7 presents the parameter estimates, significance values, and standardized coefficients (STDYX) for the within group and between group variables in the PISA 2012 assessment.

Table 7: *Estimated Parameter Values for Within and Between Group Variables Predicting Science Literacy Performance in the PISA 2012 Assessment*

Variable	Estimate	Std. Error	Estimate/ Std. Error	p value	STDYX
Gender	.530	3.350	.158	.874	.005
Program Type	6.943	2.170	3.200	.001	.422
Highest Parental Occupational Status	.110	.087	1.268	.205	.041
Highest Parental Education Level (by year)	-.019	.499	- .038	.970	-.001
Home Possessions	1.128	1.647	.685	.493	.023
School Location	8.614	5.846	1.473	.141	.161
School Size	.016	.018	.853	.393	.133
Student–Teacher Ratio	-3.662	.909	- 4.028	.000	-.496

As presented in Table 7, program type (γ = .422) for students and student–teacher ratio (γ = –.496) for schools demonstrate statistically significant direct effects on science literacy (p<.01). Among all variables, student–teacher ratio has the highest standardized path coefficient with science literacy scores. Findings from the model suggest that science literacy scores increase by 6.943 points with a one-unit rise in program type but decrease by 3.662 points when the student–teacher ratio rises by the same amount. Accordingly, in the established model, student–teacher ratio emerges as the strongest predictor of science literacy performance. Table 8 presents the parameter estimates, significance values, and standardized coefficients (STDYX) for the within group and between group variables in the PISA 2015 assessment.

Table 8: *Estimated Parameter Values for Within and Between Group Variables Predicting Science Literacy Performance in the PISA 2015 Assessment*

Variable	Estimate	Std. Error	Estimate / Std. Error	p value	STDYX
Gender	4.119	2.562	1.608	.108	.037
Program Type	18.482	8.599	2.149	.032	.190
Highest Parental Occupational Status	.350	.075	4.696	.000	.127
Highest Parental Education Level (by year)	-.648	.301	-2.157	.031	-.053
Home Possessions	2.433	1.489	1.634	.102	.051
School Location	18.614	4.880	3.814	.000	.456
School Size	-.043	.015	-2.764	.006	-.036
Student–Teacher Ratio	2.180	1.560	1.398	.162	.229

As presented in Table 8, parental occupational status (γ = .127) among student variables, along with school location (γ = .456) and size (γ = –.036) among school variables, exhibit statistically significant direct impacts on science literacy ($p< .01$). Among these variables, school location has the highest standardized path coefficient with science literacy scores. Findings from the model suggest that when parental occupational standing increases by one unit, students' performance in science literacy increases by 0.350 points. In a similar way, each unit rise in school location is linked to an 18.614-point gain, while every unit expansion in school size is associated with a 0.043-point reduction in science literacy performance. Accordingly, school location emerges as the most influential factor for science literacy outcomes within the model. Table 9 presents the parameter estimates, significance values, and standardized coefficients (STDYX) for the within group and between group variables in the PISA 2018 assessment.

Table 9: *Estimated Parameter Values for Within and Between Group Variables Predicting Science Literacy Performance in the PISA 2018 Assessment*

Variable	Estimate	Std. Error	Estimate / Std. Error	p value	STDYX
Gender	4.176	2.728	1.531	.126	.035
Program Type	-6.878	2.896	- 2.375	.018	-.218
Highest Parental Occupational Status	.463	.073	6.318	.000	.181
Highest Parental Education Level (by year)	-.649	.383	-1.694	.090	-.047
Home Possessions	1.662	1.432	1.161	.246	.031
School Location	20.686	6.332	3.267	.001	.358
School Size	.017	.021	.803	.422	.093
Student–Teacher Ratio	-.650	1.772	- .367	.714	-.053

Table 9 shows that at the student level, highest parental occupational status (γ = .181), and at the school level, school location (γ = .358), exert statistically significant direct effects on science literacy performance ($p< .01$). Among all variables, school location has the highest standardized path coefficient with science literacy scores. Findings from the model suggest that science literacy improves by 0.463 points for every one-unit increase in parental occupation, while a unit change in school location yields a 20.686-point rise. Accordingly, within the model, school location emerges as the strongest predictor of science literacy performance. A systematic comparison of the significant predictors of science literacy across the 2003, 2006, 2009, 2012, 2015, and 2018 PISA cycles for

Türkiye is presented in Table 10 to highlight the stability and consistency of these variables over time.

Table 10: *Systematic Comparison of Significant Predictors of Science Literacy Across PISA Cycles (2003–2018)*

Variable	2003	2006	2009	2012	2015	2018
Student level						
Gender						
Program Type				Sig.		
Highest Parental Occupational Status	Sig.	Sig.			Sig.	Sig.
Highest Parental Education Level (by year)						
Home Possessions		Sig.	Sig.			
School level						
School Location		Sig.	Sig.		Sig.	Sig.
School Size					Sig.	
Student–Teacher Ratio	Sig.		Sig.	Sig.		

Table 10 provides a systematic comparison of the significant predictors across six PISA cycles. The consistent presence of 'Highest Parental Occupational Status' at the student level and 'School Location' at the school level highlights their role as stable predictors of science literacy in Türkiye over the 15-year period.

Discussion

Across all PISA cycles from 2003 to 2018, a significant share of the variation in Turkish students' science literacy performance is explained by differences between schools. According to OECD (2005), the 2003 PISA results highlighted Türkiye as the system in which between-school variation had the greatest association with student achievement. In line with this, Dolu's (2018) analysis of PISA 2015 data on educational equity in Türkiye demonstrated that a majority of the variance in science literacy performance was linked to disparities between schools. Drawing on multivariate multilevel analyses of PISA data, Ötken (2019) demonstrated that, in both 2009 and 2012, the predominant share of variance in science literacy outcomes was explained by differences among schools. Likewise, Acar (2012), using data from the Turkish sample of PISA 2009, concluded that students' science literacy scores varied significantly across schools. Such outcomes correspond with the findings of the present research, emphasizing the considerable effect of school-level factors on science literacy performance. Considering that the vast majority of PISA participants are high school students, it is not surprising that differences between schools are high. In Türkiye, students are placed in high schools based on certain criteria, which results in academically similar students being clustered in the same schools. This process may contribute to differences between schools while reducing within school variation among students.

This section examines the determinants of science literacy scores at the student and school levels across all six PISA cycles (2003–2018). Gender, considered as one of the student-level predictors in this study, was not a statistically significant predictor of science literacy outcomes across any of the PISA cycles. Acar and Öğretmen (2012), in their study of factors influencing Turkish students' science literacy performance in PISA

2006, similarly concluded that gender had no significant effect. The preliminary report on PISA 2015 indicated that gender did not produce a statistically significant variation in students' science literacy performance. Consistent with these results, Ötken (2019) found no significant gender differences in science literacy scores in the 2009, 2012, and 2015 cycles. These findings from the literature align with the findings of the present study. However, it is important to note that global PISA literature occasionally reveals a female advantage in science literacy, often linked to higher reading comprehension skills required for science tasks. In the Turkish context, the lack of a significant gender gap may suggest a relative balance in science engagement, though some studies suggest this could vary depending on whether the focus is on 'content knowledge' or 'procedural skills.' The absence of a consistent gender effect across all cycles suggests that gender may interact with other variables such as self-efficacy or socio-economic background, which warrants further investigation into the subtle dynamics of science achievement.

Program type, included as a student-level predictor in this study, was observed to be significantly associated with science literacy achievement exclusively in PISA 2012. In the other cycles (2003, 2006, 2009, 2015, and 2018), program type was not significantly related to science literacy. Analyzing the 2009 PISA dataset, Shelley and Yıldırım (2013) reported that program type was not a statistically significant determinant of science literacy outcomes. Similarly, Ötken (2019), analyzing data from PISA 2009, 2012, and 2015, reported no significant association between program type and science literacy. Studies conducted by Ataş and Karadağ (2017), Jehangir et al. (2015), and Kim (2018) also demonstrated the absence of a significant relationship between school type and student achievement. However, some studies have found significant relationships between program type and science performance (Aksu et al., 2017; Ceylan, 2009; Usta & Çıkrıkçı Demirtaşlı, 2014). It should also be noted that the association between school type and science performance in Türkiye may reflect disparities in resources and opportunities across school types.

Findings from this study indicate that "highest parental education level (measured in years)" as a student-level variable did not exert a statistically significant influence on science literacy outcomes in any PISA cycle between 2003 and 2018. Ötken's (2019) analysis showed that maternal education did not significantly affect science achievement in the 2009 and 2012 PISA assessments; however, a statistically significant effect was identified in the 2015 cycle. Several studies have reported associations between parental education and academic achievement (Boztunç, 2010; Kurt, 2010; Özer, 2009), particularly paternal education (Anıl, 2009; Karabay, 2012) and maternal education (Aydın, Erdağ & Taş, 2011; Cameron & Heckman, 2001; Gülleroğlu et al., 2014; Kotte, Lietz & Lopez, 2005; Schulz, 2005; Yıldırım, 2012). However, the literature reveals mixed results on this matter. Findings from the current research suggest that students' science literacy achievement is not invariably aligned with parental education levels.

According to the results of this study, the student level variable "highest parental occupational status" significantly predicted science literacy in the 2003, 2006, 2015, and 2018 PISA cycles. That this variable was a significant predictor in four of the six PISA cycles Türkiye participated in underscores its importance. Çeçen (2015), using data from PISA 2003 to 2012, reported that parental occupational status significantly predicted science literacy performance. Ziya's (2008) analysis of the Turkish PISA 2006 dataset revealed that parental occupational status was positively related to mathematics literacy performance. In parallel, Orhan (2020) demonstrated, using PISA 2015 data, that parental occupational status significantly predicted students' science literacy achievement. These patterns correspond with the findings of the present research.

The student level variable "home possessions" was found to be a significant predictor of science literacy only in the PISA 2006 and 2009 cycles. In the other cycles (2003, 2012, 2015, and 2018), no significant relationship was found. However, several studies have reported that home possessions significantly predict science achievement (Çeçen, 2015; Karabay, 2013; Sarıer, 2010; Şaşmazel, 2006; Usta, 2014; Yitik, 2019). The present study partially supports these earlier findings.

The analysis showed that, at the school level, "school location" served as a statistically significant determinant in the PISA assessments of 2006, 2009, 2015, and 2018. Being a significant predictor in four of six cycles highlights the importance of school location. Specifically, the results reveal that as the urbanization level increases, science performance scores also rise, with schools in village locations consistently representing the lowest achievement baseline. The literature also indicates a relationship between geographic location and academic achievement (Giambona & Porcu, 2015; Yüksel, 2019). Studies such as those by Acar Güvendir (2014), Oral and McGivney (2013), and Usta (2014) have shown that academic achievement is often greater in more urbanized and economically developed areas. Dinçer & Uysal Kolaşin (2009) found that students attending schools in locations with populations below 15,000 had lower scores in science, mathematics, and reading literacy. TEDMEM's 2014 Education Evaluation Report suggested that student achievement gaps between rural and urban schools stemmed from the clustering of more experienced teachers in urban institutions. Findings from the present research corroborate existing literature, showing that science literacy achievement tends to rise in urbanized contexts, possibly as a result of more abundant educational resources and a higher concentration of experienced teachers.

The school level variable "school size" significantly predicted science literacy only in the 2009 PISA cycle. Increased student enrollment was associated with decreased performance. Analyzing PISA 2009 data, Acar (2012) demonstrated that school size was a statistically significant predictor of students' science literacy performance. Ötken (2019), analyzing PISA 2015 data, also found that science performance declined as school size increased. According to Giambona and Porcu (2018), scholarly studies have not reached a consensus on how school size relates to student achievement. Cotton (1996) observed that the relationship can be either positive or negative depending on context. The present study supports the notion that larger schools may be negatively associated with science performance. Research suggests that smaller and medium-sized schools may provide environments that support stronger interpersonal communication and a greater sense of community, outcomes that are particularly important for students from lower socioeconomic backgrounds.

In the 2003, 2009, and 2012 cycles, the “student–teacher ratio,” considered as a school-related indicator, was found to be a significant determinant of science literacy performance. Science literacy outcomes decline as the ratio of students to teachers rises. Ötken (2019) found that the student–teacher ratio negatively predicted mathematics, reading, and science performance in the 2009 and 2012 cycles. Özberk et al. (2017), using PISA 2012 data, also reported a negative association with mathematics literacy. Dinçer and Kolaşin (2009), using PISA 2006 data, reached a similar conclusion regarding science literacy. Acar (2012) and Özkan (2015) also reported significant negative effects of student–teacher ratio on science performance. The 2016 Education Evaluation Report emphasized that high student–teacher ratios are negatively associated with teacher–student interaction, attention to individual differences, and instructional quality. Consistent with existing literature, the present findings demonstrate that an increase in the student–teacher ratio corresponds to reduced achievement in science literacy.

Conclusion and Recommendations

The purpose of this study was to examine student- and school-related variables to assess their predictive power for Turkish students’ science literacy outcomes in PISA cycles (2003–2018), and to establish which variables demonstrated consistent effects across assessments. Results revealed that in each of the six PISA cycles, over 50% of the variance in science literacy achievement could be explained by between-school disparities, with the remaining portion linked to individual-level differences.

Results from the 2003 PISA cycle indicated that students’ science literacy performance was associated with parental occupational status at the individual level and the student–teacher ratio at the institutional level. The student–teacher ratio was identified as the strongest determinant in the model, but its relationship with achievement was inverse.

Findings from the 2006 PISA cycle indicated that students’ science literacy performance was associated with parental occupational and home possessions status at the student level and the geographical location of the school at the contextual level. Within the model, school location proved to be the strongest determinant of achievement.

Findings from the 2009 PISA cycle showed that student-level resources, measured by home possessions, school location together with school-level factors such as location and the student–teacher ratio, contributed to differences in science literacy outcomes. Within the model, the location of the school emerged as the most significant determinant.

Findings from the 2012 PISA cycle indicated that program type was the relevant factor on the student side, while the student–teacher ratio represented the key school-level determinant. Among these variables, the ratio of students to teachers was identified as the strongest predictor of science literacy achievement.

Findings from the 2015 PISA cycle indicated that students' science literacy outcomes were associated with parental occupational status on the student side and by contextual factors such as school size and geographical region. Within the model, the region in which the school was situated emerged as the strongest determinant of performance.

Findings from the 2018 PISA cycle showed that students' science literacy performance was associated with parental occupational status on the individual side and with the geographical setting of the school at the contextual level. Within the model, school location was identified as the strongest determinant of achievement.

From these findings, key recommendations are proposed for policymakers and researchers:

Findings indicate that school-level variation in science literacy achievement was considerable in Türkiye across the 2003, 2006, 2009, 2012, 2015, and 2018 PISA assessments. Reducing such disparities requires targeted interventions, including enhanced resource allocation to schools, with priority given to less advantaged areas.

As the student–teacher ratio proved to be an important predictor, strategies should aim to decrease class density. This can be achieved by recruiting more teachers, particularly in disciplines facing shortages. Specifically, policymakers should work towards reaching the OECD average of approximately 15:1. This is especially critical in science education, where maintaining a student–teacher ratio that allows for effective laboratory supervision and individualized feedback is essential.

It has been observed that the region in which the school is located is associated with science literacy achievement, and that students attending schools in city centers have higher scores than those attending schools in towns and villages. In this context, opportunities for education in towns and villages can also be increased.

It was concluded that students attending schools with large student populations had lower science literacy scores compared to those in other schools. Given the effect of school size on student outcomes, adjustments can be made to the distribution of students across schools. Specifically, evidence from the literature suggests that maintaining school sizes within a medium range approximately 600 to 900 students can optimize academic outcomes by fostering stronger teacher–student engagement and a more supportive sense of community

The Ministry of National Education can collect data using questionnaires similar to the student and school questionnaires used in PISA assessments as part of its own measurement and evaluation practices. Drawing on the associations between questionnaire-based measures and students' test outcomes, data-driven educational policies may be formulated.

Parents with high occupational status can provide more opportunities for their children. However, students who are disadvantaged in terms of their families' occupational status are often deprived of such opportunities, which are associated with educational inequality. To reduce this inequality, resources provided to schools can be increased, starting with disadvantaged regions. Computers, internet access, and instructional materials that every student in the school can benefit from can be made available. Additionally, study rooms can be designed in schools to encourage students to engage in academic study.

This study is limited to science literacy. Additional research could be carried out in areas such as reading proficiency and mathematics literacy.

This research relied exclusively on the dataset pertaining to Türkiye. The effects of the variables used in the study on student achievement can be investigated in other countries. Comparative studies with other countries can be conducted.

The investigation was limited to PISA assessment. Comparative studies with other international assessments can also be carried out.

The study analyzed the influence of student and school characteristics on PISA achievement over successive cycles. Subsequent investigations may examine the extent to which these predictors are equally relevant for students' performance in national assessments and school-level achievement.

The analysis employed a two-level structural equation model, incorporating both student and school levels. Where appropriate data is available, future studies may incorporate classroom-level variables and extend the analysis to three-level structural equation models. In this way, similarities and differences between classrooms in terms of variables affecting academic achievement can be examined.

Limitations

Since the study aimed to cover all PISA cycles, only the variables common to all years were included in the models. However, this approach resulted in the exclusion of certain important constructs that were available only in specific cycles. These include affective variables such as science motivation, science self-efficacy, and epistemic beliefs, as well as contextual variables such as school climate and disciplinary climate. Given that science literacy encompasses both cognitive and affective dimensions, the exclusion of these constructs may limit the explanatory power of the model. Finally, the analysis was restricted to two levels — student and school — due to the absence of classroom-level data in the PISA dataset, which may have resulted in the omission of potentially important teacher and classroom characteristics.

Ethical Approval

We declare that the study has no unethical problems, and there is no need for ethics committee approval since the research is based on publicly available open data provided by the OECD.

Author Contributions

Bilge Acar: Conceptualization, Theoretical Background, Methodology, Data Analysis, Data Visualization, Writing

Selahattin Gelbal: Conceptualization, Theoretical Background, Methodology, Review and Editing

Conflict of Interest

The authors declare no conflict of interest.

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