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An analysis of factors affecting Mongolian students' performance in science and mathematics: Evidence from PISA data

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Abstract

This study analyzes Mongolian students' performance in science and mathematics using the PISA-2022 dataset. It identifies the main influencing factors and aims to contribute to education policy and planning. The research objective is to determine which variables are significant predictors of science and mathematics performance, based on the student characteristics and test scores collected from Mongolian students in PISA. The dataset included more than 7,000 students from 196 schools representing 4 regions and 12 strata in Mongolia, taken from the publicly available PISA 2022 dataset. Data mining and quantitative analysis methods were applied using Python programming, and some statistical calculations and data handling were conducted with Microsoft Excel. The results show that mathematics performance is the strongest predictor of science achievement. Reading literacy is also a strong predictor of both science and mathematics, although its effect on science is weaker than that of mathematics. Mother's education level, the number of digital devices, and the number of books at home have moderate to weak effects. Regional differences slightly affect performance in both science and mathematics, but the effect size is small and not practically significant.

Keywords: Academic achievement, Influencing factors, Mathematics performance, Mongolian educational system, PISA 2022, Reading literacy, Science achievement.

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Contents

Contribution of this paper to the literature
This paper contributes to the literature by providing one of the first comprehensive analyses of Mongolian students' science and mathematics performance using the PISA 2022 dataset. It identifies key academic and socioeconomic predictors, offering empirical evidence to support data-driven education policy and planning in developing education systems.

1. Introduction

Education is the main factor that determines the future development of any nation. It not only transfers knowledge but also provides the foundation for shaping citizens who are capable of contributing to society, the economy, science, and culture. Therefore, the primary goal of education is to successfully teach learners, nurturing them into individuals with intellectual, moral, and physical competence, who uphold humanistic values, and who are capable of independent learning, working, and living (Government of Mongolia, 2002).

Scientific knowledge and skills are among the essential characteristics of an educated and competent person, defining the ability to successfully participate in modern social development and global competition. Thus, creating a quality education system that supports science education is an integral part of any country's development strategy (Bybee, 1997). In recent years, the Programme for International Student Assessment (PISA), conducted every three years by the Organisation for Economic Co-operation and Development (OECD), has served as a crucial source of information for evaluating the quality of national education systems. By measuring students' performance in science, mathematics, and reading literacy, PISA provides evidence-based insights that inform educational policy and planning. For example, OECD data indicate that countries with the highest levels of student academic achievement are also those most successful in implementing policies and interventions that mitigate the effects of social disadvantage (OECD, 2022).

Reading and reading comprehension skills constitute fundamental competencies essential for lifelong learning, and numerous international and national studies have recognized them as indispensable life skills (Carnevale, Smith, & Strohl, 2013; Goodman, Finnegan, Mohadjer, Krenzke, & Hogan, 2013; Karasu & Haşıloğlu, 2020; Nouri, Åkerfeldt, Fors, & Selander, 2017; OECD Education GPS, 2022; Salas-Velasco & Sánchez-Campillo, 2018). Furthermore, extensive research demonstrates that reading comprehension is closely intertwined with a wide range of cognitive abilities. Specifically, reading comprehension has been shown to correlate positively with learning capacity, self-expression skills, and other cognitive processes (Chung, 2010; Karasu & Haşıloğlu, 2020; Proudfoot, 2016; Yasin, Mergen Gürses, & Bilişli, 2025). A number of studies have established that students' reading skills are directly associated with their academic performance across other subject areas (Barnard-Brak, Stevens, & Ritter, 2017; Bastug, 2014; Karasu & Haşıloğlu, 2020; Proudfoot, 2016; Reed, Petscher, & Truckenmiller, 2017; Yasin et al., 2025). Additionally, research consistently shows that reading, mathematics, and science achievement are strongly interrelated and that reading comprehension exerts a significant influence on students' performance in mathematics and science (Caponera, Sestito, & Russo, 2016; Hanushek & Woessmann, 2015; Koyuncu & Firat, 2020; Larwin, 2010; Ömer Cem, & Kasap, 2023).

In PISA, 15-year-old students are tested in science, mathematics, and reading, while also completing background questionnaires. These gather information about personal, social, and cultural characteristics, attitudes, behaviors, quality of life, school environment, and parental background (OECD, 2003, 2010, 2015).

Main components of PISA Data:

1. Student Assessment Data
- Reading literacy – ability to retrieve, understand, and interpret information.
- Mathematical literacy – ability to solve problems, model, and calculate.
- Scientific literacy – ability to understand scientific investigations and make evidence-based conclusions.
- In some years, additional domains are included (e.g., collaborative problem-solving, global competence, financial literacy, etc.).
2. Student Questionnaire Data
- Learning attitudes and mindset.
- Learning environment and support.
- Family socio-economic background.
- Time management and quality of life.
3. School Questionnaire Data
- School structure, policy, and management.
- Resources and teacher qualifications.
- Learning environment and discipline.
4. Teacher Questionnaire (In some years)
- Teaching practices.
- Job satisfaction and professional development.

Mongolia participated in PISA for the first time in 2022. The results showed that, while students performed relatively well in mathematics compared to some countries, their performance in science and reading was below the OECD and Asian averages, highlighting the need for focused attention on education policy. More than 7,000 students from 196 schools took part in the study (OECD, 2022).

Comparison of average scores of 15-year-old Mongolian students in PISA 2022.

1. Science (PV1SCIE): Mongolia's average score: 412, OECD average score: 485, Asian regional average score: 449 – Mongolia lags behind the OECD average by about 3 years and the Asian average by about 1.8 years (OECD Education GPS, 2022).
2. Mathematics (PV1MATH): Mongolia's average score: 425, OECD average score: 472, Asian regional average score: 451 – Mongolia lags behind the OECD average by about 2.3 years and the Asian average by about 1.2 years (OECD Education GPS, 2022).

3. Reading (PV1READ): Mongolia's average score: 378, OECD average score: 476, Asian regional average score: 427. Mongolia lags behind the OECD average by about 5 years and the Asian average by about 2.5 years (OECD Education GPS, 2022).

2. Research Objective

The objective of this study is to identify the key factors affecting Mongolian students' performance in science and mathematics based on PISA-2022 data and to evaluate the extent of their influence using statistical analysis. Ultimately, the study aims to contribute to the development of evidence-based education policy recommendations and strategies to improve the quality of education.

Within this objective, two research questions were proposed.

(1) What are the important variables that predict students' science achievement in terms of student characteristics, mathematics, and reading comprehension scores measured in the PISA student questionnaire?

(2) What are the important variables that predict students' mathematics achievement in terms of student characteristics, science, and reading comprehension scores measured in the PISA student questionnaire?

3. Research Methodology

3.1. Data Source and Structure

The study used data from more than 7,000 Mongolian students representing 196 schools across 4 regions and 12 strata who participated in PISA-2022. The original dataset was in *.sav* format and contained information on 613,732 students across 1,278 variables, including personal characteristics, family socio-economic background, school environment, and test scores.

3.2. Sampling Method

PISA uses a multi-stage, stratified random sampling approach. In the first stage, schools are selected based on regional and urban/rural representation. In the second stage, students are randomly sampled from those schools. As a result, student performance scores represent the national 15-year-old student population. PISA provides weighting coefficients (Final student weight and Replicate weights) to ensure representativeness, which can be applied in analysis (OECD, 2022).

3.3. Data Preparation and Analysis

For the purpose of the study, two objectives were set: *(1) preparing the research data* and *(2) analyzing and interpreting the data.*

1. Tasks performed in the stage of preparing the research data

- Isolated Mongolian data.
- Removed columns with more than 70% missing data.
- Removed columns with only one unique value.
- Kept only PV1*** variables, excluded PV2–PV10.
- Removed rows with missing values when less than 5% of the data was missing.
- After cleaning, the dataset contained 4,383 rows and 205 variables, covering 4 regions, 12 strata, and 195 schools (2,115 male and 2,268 female students).

In conclusion, the data, originally consisting of 613,732 rows (students) and 1,278 columns (student characteristics), was cleaned and transformed into a dataset with 4,383 rows and 205 columns. This data includes information from 4,383 students across 195 schools in Mongolia. The students were divided into 4 regions, with each region further divided into 2-4 strata (a total of 12 strata). There are 2,115 male students and 2,268 female students Table 1.

Table 1. Student's regional and gender information.

Region	Stratum	Total	Gender	Amt
Mongolia: Rest of the country	Eastern, Suburban	188	F	100
			M	88
	Eastern, Rural	101	F	59
			M	42
	Gobi, Suburban	160	F	73
			M	87
	Gobi, Rural	84	F	46
			M	38
Mongolia: Central	Central, Urban	2282	F	1156
			M	1126
	Central, Suburban	244	F	119
			M	125
	Central, Rural	178	F	93
			M	85
Mongolia: Khangai	Khangai, Suburban	430	F	237
			M	193
	Khangai, Rural	255	F	144
			M	111
Mongolia: Western	Kazakh	80	F	41
			M	39
	Western-other, Suburban	241	F	127
			M	114
	Western-other, Rural	140	F	73
			M	67

2. Tasks performed in the stage of data analysis and interpretation

Correlation analysis: To identify which variables are correlated with the science and mathematics performance indicators, PV1SCIE and PV1MATH, and to select those variables that exhibit strong, moderate, or weak positive or negative correlations, the following steps were performed.

The analysis aimed to identify the factors influencing science and mathematics performance, based on the five general categories from the PISA data: (1) Learning achievement; (2) Learning attitude and mindset; (3) Learning environment and support; (4) Family socio-economic background; (5) Time management and quality of life.

- In PISA 2022 data, the results of science and mathematics tests are represented by continuous numerical variables, PV1SCIE–PV10SCIE and PV1MATH–PV10MATH.

PV1MATH and PV1SCIE represent the most appropriate values among the 10 plausible values (PV1, PV2, ..., PV10) calculated for each student in the PISA-2018 assessment (OECD, 2019; Ömer Cem et al., 2023).

The results of the correlation analysis, which identified the factors affecting science performance (PV1SCIE), are summarized in Table 2.

Table 2. Results of correlation analysis for PV1SCIE.

Code	Correlation with PV1SCIE	Description
PV1MATH	0.845	Mathematics score
PV1READ	0.757	Reading comprehension score
HOMEPOS	0.403	Home possessions (WLE)
ESCS	0.394	Index of economic, social, and cultural status
ST253Q01JA	0.354	How many [Digital devices] with screens are there in your [Home]?
ST255Q01JA	0.313	How many books are there in your [Home]?
MISCED	0.265	Mother's level of education
ST251Q03JA	0.261	How many of these items are there at your [Home]: Rooms with a bath or shower
HISCED	0.258	The highest level of education of parents
PAREDINT	0.258	Index highest parental education (International years of schooling scale)
FISCED	0.240	Father's level of education
STRATUM	-0.0096	Stratum
REGION	-0.157	Region
ST005Q01JA	-0.282	What is the [Highest level of schooling] completed by your mother?

- The results of the correlation analysis, which identified the factors affecting mathematics performance (PV1MATH), are summarized in Table 3.

Table 3. Results of correlation analysis for PV1MATH.

Code	Correlation with PV1MATH	Description
PV1SCIE	0.845	Science score
PV1READ	0.769	Reading comprehension score
HOMEPOS	0.428	Home possessions (WLE)
ESCS	0.414	Index of economic, social, and cultural status
ST253Q01JA	0.352	How many [Digital devices] with screens are there in your [Home]?
ST255Q01JA	0.331	How many books are there in your [Home]?
ST251Q03JA	0.297	How many of these items are there at your [Home]: Rooms with a bath or shower
MISCED	0.266	Mother's level of education
PAREDINT	0.260	Index highest parental education (International years of schooling scale)
HISCED	0.257	The highest level of education of parents
FISCED	0.246	Father's level of education
STRATUM	-0.003	Stratum
REGION	-0.123	Region
ST005Q01JA	-0.295	What is the [Highest level of schooling] completed by your mother?

From the results of the two correlation analyses above, it was determined that the strongest affecting factor on science performance is mathematics knowledge and skills, followed by reading comprehension skills. For mathematics performance, the strongest affecting factor is science knowledge and skills, with reading comprehension skills being the next strongest factor. In both science and mathematics, it was observed that other student characteristics have a moderate to weak effect, and these characteristics were found to be repetitive.

- In the PISA, students are divided into four regions, and each region is further divided into two to four strata (a total of 12 strata). Additionally, to ensure the representativeness of the sample in PISA, weight coefficients (W_FSTUW) and repetition weight coefficients (W_FSTR1–W_FSTR80) are used. Since the number of students in each category varies (minimum = 80, maximum = 2,282), it was considered that this might negatively affect statistical power. Therefore, to analyze the outcomes of science (PV1SCIE) and mathematics (PV1MATH) performance by region (REGION) and stratum within the region (STRATUM), the weight coefficient suggested by PISA (W_FSTUW) was used.

When comparing the differences in PV1SCIE and PV1MATH by region and stratum, both with and without the weight coefficient, no significant differences were observed.

From here, the following variables were selected for conducting a multiple linear regression analysis (Table 4).

Table 4. Variables used in Multiple linear regression analysis.

Code	Description	Category
PV1SCIE	Science score	Learning achievement
PV1MATH	Mathematics score	Learning achievement
PV1READ	Reading comprehension score	Learning achievement
HOMEPOS	Home possessions (WLE)	Quality of life.
ESCS	Index of economic, social, and cultural status	Family socio-economic background
ST253Q01JA	How many [Digital devices] with screens are there in your [home]?	Learning environment and support
ST255Q01JA	How many books are there in your [Home]?	Learning environment and support
MISCED	Mother's level of education	Family socio-economic background
ST251Q03JA	How many of these items are there at your [Home]: Rooms with a bath or shower	Learning environment and support
HISCED	The highest level of education of parents	Family socio-economic background
PAREDINT	Index highest parental education (International years of schooling scale)	Learning environment and support
FISCED	Father's level of education	Family socio-economic background
REGION	Region	Family socio-economic background
ST005Q01JA	What is the [Highest level of schooling] completed by your mother?	Family socio-economic background

Multiple linear regression analysis**:** For the selected variables, the direction and strength of their effect on science and mathematics performance were evaluated, and the statistical results were validated using indicators such as R^2, *Adjusted* R^2, and *P-value.*

a. Multiple linear regression results for PV1SCIE
   Key indicators of the multiple linear regression results.

- R-squared: 0.746: The model's $R^2 = 74.6\%$ indicates that 74.6% of the variation in the PV1SCIE variable is explained by the model, while the remaining 25.4% is due to other factors or variables outside the model. This suggests that the model is very good.
- Adj. R-squared: 0.745: When using multiple variables, the adjusted R-squared is used to evaluate the model's performance. This indicates that the model can explain 74.5% of the variance in the results.
- F-statistic: 986.5, Prob (F-statistic): 0.00: This confirms that the model is statistically significant. In other words, the model is reliable and has a real effect.

Effect of variables

- *PV1MATH: 0.5790 (P-value: 0.000)* – PV1MATH is a significant variable, and an increase of 1 unit in PV1MATH tends to increase PV1SCIE by 0.5790 units.
- *PV1READ: 0.2551 (P-value: 0.000)* – PV1READ also has a positive effect; a 1-unit change in this variable increases PV1SCIE by 0.2551 units.
- *HOMEPOS: 0.6982 (P-value: 0.617)* – The home possessions index has a weak effect on PV1SCIE. Given its P-value of 0.617, it is not statistically significant.
- *ESCS: -1.4891 (P-value: 0.286)* – Although ESCS has a negative effect, its P-value of 0.286 indicates that it is not statistically significant.
- *ST253Q01JA: 1.4200 (P-value: 0.000)* – The number of screen devices available at home has a positive effect, tending to increase PV1SCIE by 1.42 units.
- *ST251Q03JA: -2.9631 (P-value: 0.011)* – The number of bathrooms at home has a negative effect; a 1-unit change in this variable tends to decrease PV1SCIE.
- *REGION: -3.0492 (P-value: 0.000)* – The region variable has a negative effect, where a one-unit change in REGION tends to decrease PV1SCIE by 3.0492 units.

Residual analysis

- *Durbin-Watson: 2.013* – No autocorrelation present; the assumption is well met.
- *Omnibus = 8.976, p = 0.011* – The residual distribution deviates slightly from normal.
- *Jarque-Bera = 10.557, p = 0.005* – The residual distribution deviates slightly from normal.

b. Multiple linear regression results PV1MATH (excluding PV1SCIE):

Key Indicators of the multiple linear regression results.

- *R-squared: 0.616*: The model's $R^2 = 61.6\%$, indicating that 61.6% of the variation is explained by the model, while the remaining 38.4% is due to other factors or variables. This suggests that the model is sufficiently good.
- *Adj. R-squared: 0.614*: This shows that the model can explain 61.4% of the results.
- *F-statistic: 583.0, Prob (F-statistic): 0.00***.** This confirms that the model is statistically significant.

Effect of variables

- *PV1READ: 0.7867 (P-value: 0.000)* – PV1READ is a significant variable; an increase of 1 unit in PV1READ increases PV1MATH by 0.7867 units.
- *HOMEPOS: 3.8868 (P-value: 0.039)* – HOMEPOS has a positive effect; a one-unit change in this variable tends to increase PV1MATH by approximately 3.89 units.
- *ESCS: 3.0435 (P-value: 0.105)* – ESCS has a positive effect, but since its P-value is 0.105, it is weakly statistically significant.
- *ST253Q01JA, ST255Q01JA, ST251Q03JA:* These variables have a positive effect on mathematics performance.
- *ST005Q01JA: -3.5303 (P-value: 0.001)* – ST005Q01JA has a negative effect, and for each unit increase in this variable, the mathematics score (PV1MATH) tends to decrease. This variable represents the highest level of

the mother's education, which is inversely coded. Therefore, as the mother's education level increases, the child's mathematics score increases. This variable is statistically significant.

- *REGION: 2.6418 (P-value: 0.000)* – The region has a positive effect, and for each unit change in this variable, PV1MATH tends to increase by 2.6418 units.

Residual analysis

- *Durbin-Watson: 1.984* – No autocorrelation present; the assumption is well met.
- *Omnibus* $= 9.248$, $p = 0.010$ – The residual distribution deviates slightly from normal.
- *Jarque-Bera* $= 9.157$, $p = 0.0103$ – The residual distribution deviates slightly from normal.

3.4. Findings

3.4.1. Correlation Analysis

- The strongest factor correlated with science achievement (PV1SCIE) was the mathematics score ($r = 0.845$), followed by the reading comprehension score ($r = 0.757$).
- The strongest factor correlated with mathematics achievement (PV1MATH) was the science score ($r = 0.845$), followed by the reading comprehension score ($r = 0.769$).
- Socio-economic indicators and parental education levels showed medium to weak correlations.

3.4.2. Multiple Linear Regression Analysis

- Model for Science achievement: Mathematics score ($\beta = 0.579$, $p < 0.000$) and reading comprehension score ($\beta = 0.255$, $p < 0.000$) had the strongest positive effects. $R^2 = 0.746$ – The model explains 74.6% of the variance in science scores. *Adjusted* $R^2 = 0.745$ – The model is robust. *F-statistic significant* – The model is statistically valid.
- Model for Mathematics achievement: Reading comprehension score ($\beta = 0.787$, $p < 0.000$) had the strongest positive effect. $R^2 = 0.616$ – The model explains 61.6% of the variance in mathematics scores. Adjusted $R^2 = 0.614$ – The model is sufficiently good. F-statistic significant – The model is statistically valid.
- Regional differences were statistically significant but had a small effect size.
- Socio-economic background and parental education have positive but moderate to weak effects.

4. Discussion

The findings of this study show that Mongolian students' science achievement strongly depends on their mathematics and reading comprehension skills. Previous PISA-based studies in other countries have also found that these two competencies are the most important predictors of science performance, and the same trend is confirmed for Mongolia. This highlights the need for strategies that develop mathematics and reading comprehension skills together in order to improve science outcomes.

Family background indicators, such as parents' education level and the number of books at home, have positive but relatively weak effects on science performance. This result aligns with international research based on PISA data, which suggests that while the family environment influences academic achievement, its effect is generally weaker compared to the influence of the school environment, quality of teaching, and students' own learning abilities.

The differences in the regions where students live have varying effects on their achievement in science and mathematics. However, the magnitude of the regional effect on science and mathematics is small and does not appear to cause a noticeable difference in real-world contexts. This suggests that the disparities in academic outcomes among Mongolian students are less related to geographical location and more related to individual skills and learning conditions.

The number of digital devices at home has shown effects on both science and mathematics achievement. This raises questions about the relationship between technology use and learning habits. Rather than focusing on restricting screen time, the results suggest the importance of developing effective ways of using technology to positively support learning and education.

5. Conclusion and Recommendations

The findings of the study reveal the following key conclusions.

1. Mathematics skills were found to be the strongest predictor of science achievement.
2. Reading literacy strongly predicts both science and mathematics performance, but its effect on science is weaker than that of mathematics.
3. Regional differences were statistically significant in relation to academic achievement, but the effect size was small.
4. Socio-economic indicators and parental education levels have a moderate to weak positive influence on students' academic outcomes.

These results provide the basis for advancing the following evidence-based recommendations in the development of educational policies and curricula. These include.

1. Integration and coherence of foundational competencies

- The parallel development of mathematical and reading competencies serves as a crucial determinant of achievement in science. Therefore, it is recommended that curriculum frameworks incorporate pedagogical approaches grounded in the integration of these core skills.
- Strengthening interdisciplinary linkages across subjects is essential to foster students' ability to interpret and solve scientific problems through the combined use of quantitative and textual information.

2. Enhancing family support and parental engagement

- Increasing parental participation in the learning process can play a pivotal role in improving student achievement.

- Policies should aim to enhance access to books, learning resources, and supportive tools that facilitate effective learning both at home and in school environments.

3. Policies to promote equity in education

- To reduce socio-economic disparities and ensure equitable quality of education across urban and rural areas, the optimization of the allocation of educational resources and targeted support is necessary.
- Expanding intervention programs designed to support students from low-income and socio-economically vulnerable groups is strongly recommended.

4. Responsible use of technology and development of information literacy

- The utilization of digital technologies and screen-based tools should be strategically managed to enhance learning outcomes rather than detract from them.
- Students should be systematically trained to engage with information critically and responsibly, and to use artificial intelligence tools in an ethical and informed manner.

5. National assessment and evidence-based policymaking

- Establishing and regularly implementing national-level assessments analogous to the PISA framework would provide robust evidence for policy formulation and evaluation.
- Such assessments should be developed not merely as instruments to monitor regional disparities but as tools to measure progress in foundational competencies and to evaluate the effectiveness of educational interventions and policies.

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