Application of multivariate regression analysis for assessing the relationship of students’ backgrounds to students’ achievements

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**Abstract**. Mathematical skills are one of the most important abilities for students, especially when faced with the Industrial Revolution 4.0 era as wells as skills in science and reading. This study aims to examine the relationship of students’ backgrounds on mathematics, science and reading achievement using PISA 2018 Indonesia for Daerah Istimewa Yogyakarta (DIY) Province. The DIY province is known as the home for a large student population and many schools and universities. The multivariate linear regression analyses revealed that there was a statistically significant relationship between gender and index of economic, social and cultural status (ESCS) on mathematics, science and reading achievements. The results of multiple linear regression indicated that girls have higher score in math, science and reading scores than boys with the existing linear up trend for ESCS that increases their scores for achievements.

1. Introduction

Industrial Revolution 4.0 marked fundamental changes in the second decade of the 21st century. The critical cause of these changes is rapid developments in technology: the Internet of Things (IoT), Artificial Intelligence (AR), and Big Data. Several competencies are needed to maintain the human role in this disruption era, e.g. mathematical competence, reading competence, science, problem-solving, and many more.

Mathematics is an essential competency needed to solve various daily problems and complex industrial situations. Science allows students to explore their world and discover new things, making it an important part of the foundation for all children’s education [1]. In addition to reading skills, mathematics and science ability are evaluated through an international test known as the Programme for International Student Assessment (PISA). This test is held once every three years by the Organization of Economic Cooperation and Development (OECD), with a focus on the one of three competences. Apart from the examination, the students also fulfill several questionnaires related to their family, daily routine, household, experiences and others [2].

Several PISA studies have been performed in Indonesia and other countries, especially related to mathematics and science skills. Karakolidis *et al*. [3] used binary multilevel modeling to analyze factors affecting the achievement of low mathematics at PISA 2012, and factors differentiating students who achieve high to low scores. Perera [4] studied the influence of parents’ factor on students' performance of the PISA test in the science field. Sun *et al*. [5] used multilevel analysis to determine factors affecting the science achievement of high school students in Hong Kong using data from PISA 2009. Anderson et al. [6] analyzed the mathematical literacy of students in some countries with a result of PISA 2006 using a hierarchical linear modeling method. Pakpahan [7] used correlation analysis on PISA 2012 data and found that identity, socioeconomic and cultural conditions, computer ownership, and books were the main factors influencing the Indonesian students' mathematical literacy. Kartianom and Ndaziyeye applied the multilevel model and found that the socioeconomic status of the family, the socioeconomic average of the school, and students' sense of belonging to mathematics affects the achievement of students' score in mathematics ability at PISA 2015 [8]. Comparison can be rendered across countries, for example by identifying factors influencing mathematics performance in Indonesian, Turkish, Australian and Dutch students [9]. All of the studies listed show that the PISA survey yields a lot of information related to educational quality in a country.

The results of the PISA 2018 test show that students from Daerah Istimewa Yogyakarta (DIY), a province in Indonesia, exhibit somewhat different performance compared to students from around the country. In mathematics, DIY students obtain an average score of 422, 6 points higher than the students from DKI Jakarta, or 43 points higher than the entire Indonesian participants. Students from DIY also outperform the other provinces in terms of science and reading skills [10]. This result is similar to the 2017-2019 National Examination for Junior Secondary School, in which students from this province have the highest average score in mathematics, science and national language across all provinces in Indonesia [11]. For a long time, DIY is known as the home for many schools, students, and higher education institutions (universities and academies). As a former kingdom governed by Sultan, various ceremonial and cultural events still occurred in DIY. This province is also known for its population’s highest life expectancy [12], but with high economic inequality as presented by high value of Gini Ratio [13].

The PISA 2018 might not only give information about the score and rank obtained by students from DIY or, more generally, Indonesia. This study aims to explain the relationships between gender and economic-social-cultural status (ESCS) to the students’ performance in reading, mathematics, and science using the PISA 2018 datasets. To reduce the variability, this study focuses on the score that obtained by students from DIY. Result of this study could provide some insights for further analysis of PISA 2018 datasets.

1. Materials

## Data

Data used in this study were taken from the Programme for International Student Assessment (PISA) 2018 which available online through the www.oecd.org/pisa website. PISA measures 15-year-olds’ ability to use their reading, mathematics and science knowledge and skills to fulfill real-life challenges [14]. The PISA 2018 Indonesia for Daerah Istimewa Yogyakarta (DIY) province data were selected to examine the relationship of students’ backgrounds to students’ achievements.

## Measures

The outcome variables in this study are mathematics, science, and reading achievements where each outcome is calculated from the average of its ten of the plausible values. The explanatory variables are gender (female and male) and the index of economic, social, and cultural status (ESCS). The ESCS index was created using student reports on parental occupation, the highest level of parental education, and an index of home possessions related to family wealth, home educational resources and possessions related to classical culture in the family home [15].

## Data Analyses

In this study a total of 1,856 students on the selected variables with completes responses were used in the analyses. Descriptive statistics, multivariate regression analysis without and with interaction were used to overview characteristics of the sample and to assess the relationship of gender and ESCS on the three student achievements simultaneously and separately.

The multivariate linear regression model in matrix form is given below,

(1)

where is the responses matrix with observations and responses, is the design matrix where the values of can be placed as the matrix , is the regression coefficient matrix and isthe error matrix.

The assumptions of model are and, [16]. Using analogy with the univariate least square estimate, the estimate of is given below,

. (2)

The matrices of the predicted values and residuals can be obtained using the least square estimates as follows,

predicted values:

residuals: (3)

In data analyses, lm function in stats package in R is used to fit the multivariate linear regression model. The mvn function in MVN package in R is used to examine multivariate normality along with the multivariate plots [17].

1. Results

The total of the samples (=1,856) included in this study are 928 boys and 928 girls. Table 1 presents information about the gender-based continuous variables. From the descriptive statistics in table 1, it can be seen that girls have higher reading mean scores (, ) than boys. The same results reveal a small difference between girls and boys in mathematics and science mean scores. Moreover, the variability of reading, math, and science score between female is somewhat lower than the boys.

**Table 1**. Descriptive statistics for the variables of interest

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Mean | | Standard Deviation | | Minimum | | Maximum | |
| Variable | Male | Female | Male | Female | Male | Female | Male | Female |
| ESCS | -1.27 | -1.35 | 1.10 | 1.07 | -4.12 | -3.95 | 1.34 | 1.37 |
| Math | 418.44 | 443.02 | 85.80 | 76.44 | 176.52 | 188.22 | 677.82 | 665.48 |
| Science | 427.78 | 451.55 | 72.50 | 67.15 | 231.30 | 235.73 | 626.51 | 641.35 |
| Reading | 392.29 | 435.29 | 82.81 | 73.67 | 202.06 | 215.53 | 645.91 | 656.96 |

## Relationship between gender and ESCS on the combined students’ achievements

A multivariate linear regression analysis was conducted to explore the relationship between gender and ESCS on students’ achievements (mathematics, science and reading). Preliminary assumption testing was performed to check the homoscedasticity and multivariate normality. The plot of standardized residual versus predicted value is useful for checking the assumption of homoscedasticity. In this plot, if the red line in the horizontal () is flat and horizontal with equally randomly spread data points, then the homoscedasticity is satisfied. However, if the data points are not randomly spread out, then this assumption is violated. Figure 1 a) and b) show horizontal lines with randomly scattered data points around the red line, suggesting that the homoscedasticity assumption for the two models are satisfied.

|  |
| --- |
| a) Without interaction |
| b) With interaction |

Figure 1. Plot of standardized residuals vs fitted values for each outcome

In this study, it is useful to analyze a multivariate plot (i.e. Chi-Square Q-Q plots) along with a multivariate normality test to reach a more reliable decision. The Henze-Zirkler’s tests indicate that the multivariate residuals for model without interaction (=1.040, ) and model with interaction () follow the multivariate normality at significant level 0.05. The Chi-Square Q-Q plots show small deviations from the straight line indicating the satisfying multivariate normality (Figure 2).

|  |  |
| --- | --- |
| a) Without interaction | b) With interaction |

Figure 2. Chi-Square Q-Q plots for combined residuals

A multivariate regression was performed utilizing gender and ESCS as predictors in order to determine if students’ achievements (math, science, reading scores) could be predicted as a function of gender and ESCS. The analyses of model without interaction were found to be statistically significant affecting math (, ), science (, ) and reading ()), indicating that gender and ESCS are good predictors of the math, science and reading. The adjusted- square values range from 0.171 to 0.202 indicating that the percentage of variation explained by the explanatory variables to the outcome is small on each outcome. The low value in social science or education research is acceptable [18]. In addition, a significant multivariate effect on the combined achievements for gender was also found with , p<0.001, Pillai = 0.130 and for ESCS was found with , p<0.001, Pillai = 0.162. Moreover, the interactions of gender and ESCS on each outcome were not significant at 5%, indicating that no interaction effect is supported by the two-sided p-value for the test. This result suggests that the model without interaction term is preferable than the model with interaction.

**Table 2**. Multivariate linear regression analyses for the combined outcomes

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Explanatory  variables | Without interaction | | | With interaction | | |
| Math | Science | Reading | Math | Science | Reading |
| Intercept | 482.703  (3.273)\*\*\* | 485.229  (2.821)\*\*\* | 472.189  (3.177)\*\*\* | 481.617  (3.960)\*\*\* | 485.127  (3.413)\*\*\* | 471.233  (3.843)\*\*\* |
| Gender  Female (ref)  Male | -27.058  (3.474)\*\*\* | -25.866  (2.995)\*\*\* | -45.295  (3.372)\*\*\* | -25.011  (5.451)\*\*\* | -25.674  (4.699)\*\*\* | -43.494  (5.291)\*\*\* |
| ESC | 29.395  (1.603)\*\*\* | 24.951  (1.382)\*\*\* | 27.337  (1.556)\*\*\* | 28.590  (2.301)\*\*\* | 24.875  (12.539)\*\*\* | 26.629  (11.921)\*\*\* |
| Gender\*ESCS |  |  |  | 1.564 (3.209) | 0.147 (2.766) | 1.376 (3.115) |
| Adjusted | 0.172 | 0.173 | 0.202 | 0.171 | 0.172 | 0.202 |
| F-value | F(2,1853)  = 193.1\*\*\* | F(2,1853)  = 194.5\*\*\* | F(2,1853)  = 235.7\*\*\* | F(3,1852)  = 128.8\*\*\* | F(3,1852) =  129.6\*\*\* | F(3,1852) =  157.1\*\*\* |

*Note*: Parameter estimate and standard errors listed in parentheses, significance \*\*p<0.05, \*\*\*p<0.001

## 3.2 Relationship between gender and ESCS on each student achievement separately

Table 1 provides the regression coefficients along with the standard errors for each outcome. As the interaction effect is not significant, the interpretations are focused in the model without interaction.

(4)

(5)

(6)

where gender is coded as 0 = Female, 1 = Male, and ESCS is measured in units. Student’s math score is 27.058 higher for males than females and increased 29.395 points for each unit of ESCS. Student’s science score is 25.866 higher for males than females and increased 24.951 points for each unit of ESCS. Student’s reading score is 45.295 higher for males than females and increased 27.337 points for each unit of ESCS. Both gender and ESCS were significant predictors for math, science and reading separately. Figure 3 shows that in general girls have higher scores in math, science and reading than boys. The linear trend exists in each plot in figure 3, indicating the score increases as ESCS increases.



**Figure 3**. Plots between ESCS and mathematics, science, and reading scores based on gender.

1. Discussion

This study describes the relationship of gender and index of economic, social and cultural status of the students on their skills in mathematics, science and reading. This study used PISA 2018 Indonesia for Daerah Istimewa Yogyakarta (DIY) province and analyzed using multivariate linear regression method. The DIY province is known as home to a large population and to dozens of schools and universities. The linear relationships are significant for male gender (p<0.001) and ESCS (p <0.001) to each achievement. The student with better economic, social and cultural status shows higher in mathematics, science and reading scores, where girls outperform than boys. The existing gender differences in mathematics is similar to a previous study by Close and Shiel [19] and the significant socio-economic and cultural conditions effect on mathematics achievement is inline with the previous result from Pakpahan [7]. Fonseca *et al.* [20] reported the relationship between gender and ESCS to science achievement, whereas Naumaan and Salzer [21] showed in reading achievement.

To obtain the whole figure of relations between ESCS and gender to students’ performance in Indonesia, these results should be compared with the overall Indonesian results. Several other variables available in PISA 2018 could be explored, for example parents’ education, collection of books, and students’ facilities at home. Following some previous studies such as [8] and [22], several variables in school level can be added into the model, for example school size, school average ESCS, ratio between student and teacher, sex ratio between students, and school facilities. As a consequence, another method such as multi-level analysis can be used to analyse the data.

1. Conclusion

The multivariate linear regression analyses suggested that all significant relationship for gender and index of economic, social and cultural status to mathematics, science and reading. The higher the student’s index of economic, social and cultural status, the higher the scores in mathematics, science, and reading. Girls tend to attain higher scores than boys. The backgrounds of the students have a relation to increasing the achievements of the students.

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