A data science approach to identify crucial factors of predicting test performance in Program for International Student Assessment

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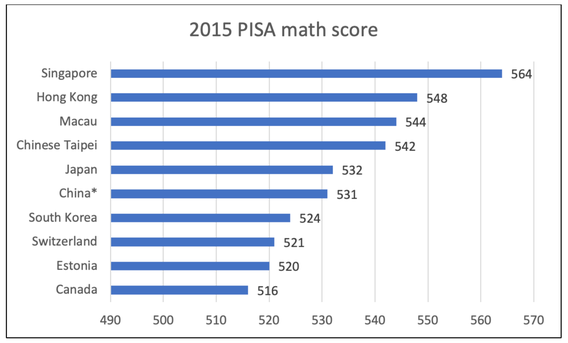
Abstract

The test results of Programme for International Student Assessment (PISA) have been utilized for benchmarking and informing education practice since 2000. The objective of this study is to identify the most important predictors of test performance in PISA math tests among top-performers. However, these big data collected from nations and regions across the globe poise challenge to traditional statistics, which tends to report false claims when the sample size is large and is restrictive by parametric assumptions. To rectify the situation, in this study data science methods was employed to analyze 2015 PISA data (*n* = 78,488). This sample is a subset of the entire PISA data set. Specifically, only observations from the top performing countries and regions were extracted. The US sample was also included in order to examine whether the US model is different from the top-performer models. It was found that out of 611 variables, which are under different categories (e.g. parent, household environment, teacher, school resources, technology, student…etc.), only fewer than 10 factors can predict the test outcome in each selected country/region. In addition, while both Hong Kong and Japan show common themes among the most important predictors, the results of Singapore and USA are complex.

Problem and Purpose

In this study the data are sourced from Programme for International Student Assessment (PISA). Since 2000, PISA administered by Organization for Economic Cooperation and Development (OECD) has delivered tests to 15-year-old students recruited from their member and non-member countries every three years. PISA exams are scenario-based. Specifically, PISA exams emphasize deduction, inference, and application in ways that may not directly be found in textbooks, such as finding the best route on a subway map in terms of time spent in travelling and costs, assigning participants to dorm rooms in a summer camp given certain rules and regulations, troubleshooting a malfunctioning irrigation system (Csapó & Funke 2017). OECD countries realize that these days, most manual or routine cognitive tasks can be performed either by cheaper laborers or by computers; thus they expect that the demand for these types of jobs will continue to migrate from OECD countries to developing nations. In order for OECD citizens to fully participate in the process of globalization, there are some critical skills that emerging adults must possess: advanced problem-solving skills that go beyond just following protocols and fluent communication skills to illustrate complex scientific ideas in a user-friendly fashion. PISA has acknowledged a need for these skills and based on its educational philosophy. PISA items are designed to test students' ability to apply knowledge to various contexts rather than simply recalling names and terms (OECD, 2007).

The US performance ranking was low in PISA tests. In 2015, the US ranked 38th in math and 24th in science, out of 71 total countries. Among the 35 OECD members, the US ranked 30th in math and 19th in science. The top performers of PISA were Asian countries and regions, including Singapore, Hong Kong, Macau, Taiwan, Japan, China (Shanghai), and South Korea. Hence, the focus of this study is to compare the US and some Asian nations/regions in terms of the crucial factors to predict PISA math performance.



Significance

Why is math performance important? First, the Bureau of Labor Statistics (US Department of Labor, 2017) forecast that the fastest growing jobs from 2016 to 2026 in the US would require a solid foundation in mathematics, science, and technology. Second, even if the student does not choose science and math as his/her career path, longitudinal research in the UK reveals that people with low math skills are more likely to be at risk of poor mental and physical health. To be specific, men with poor numeracy were more at risk of depression, were disinterested in politics, and also were more likely to have been suspended by school, arrested, or cautioned by the police. Women with poor numeracy had similar problems, and were also more likely to report poor physical health, to have low self-esteem, and to perceive that they lacked control over their lives (Parsons & Bynner, 2005).

Method

Because the sample size is very large, traditional statistical methods, such as OLS regression analysis, would lead to overfitting and inflated Type I errors. In addition, the regression result, which is based upon a single analysis, might be unstable across different samples, meaning that the result may not be replicable. As a remedy, gradient boost trees were employed into the analyses. As the name implies, this method gradually improve (boost) the model by repeated analyses of sub-samples.

Results (Partial)

不要輸在起跑點 ×
Bùyào shū zài qǐpǎo diǎn
Don't lose at the starting point

PISA: Hong Kong

Term	Number of Splits	SS	Portion
DURECEC: Duration in early childhood education and care	28	613279.625	0.8353
PA029Q01NA: How many hours per week did your child attend a pre-primary education arrangement at the age of three years?	25	72528.4495	0.0988
PA027Q01NA: At what ages did your child attend a pre-primary education arrangement prior to grade 1?	22	48423.9351	0.0660

PISA: Singapore

Term	Number of Splits	SS	Portion
ST059Q03TA: Number of class periods required per week in science	7	16843748.4	0.2946
ST013Q01TA: How many books are there in your home?	3	7076026.02	0.1238
ST064Q01NA: I can choose the school science course(s) I study.	3	6372589.13	0.1115
ST121Q01NA: Motivation: Gives up easily when confronted with a problem and is often not prepared	3	5634120.15	0.0986
IC008Q12TA: Use digital devices outside school for uploading your own created contents for sharing	3	4031342.53	0.0705

PISA: Japan

Term	Number of Splits	SS	Portion
IC011Q08TA: Frequency of use at school: Doing homework on a school computer.	50	457635.7	0.5602
IC011Q09TA: Frequency of use at school: Using school computers for group work and communication with other students.	3	312989.988	0.3832
IC011Q04TA: Frequency of use at school: Download\upload\browse schools web (e.g. <intranet>).	47	30075.1038	0.0368
IC011Q05TA: Frequency of use at school: Posting my work on the schools website.	50	16174.5408	0.0198

PISA: USA

Term	Number of Splits	SS	Portion
ST013Q01TA: How many books are there in your home?	8	14729503.3	0.2853
REPEAT: : Grade Repetition	10	9837783.37	0.1905
ST121Q01NA: Motivation: Gives up easily when confronted with a problem and is often not prepared	6	6209281.09	0.1203
ST076Q10NA: Before going to school did you: Work for pay	4	4579845.12	0.0887
SCIEEFF: Science self-efficacy (WLE)	4	3121990.26	0.0605

Discussion and Conclusion

The Hong Kong sample shows that the key to better math performance is to start early. There is an idiom in Hong Kong: **Do not lose at the starting point**. However, this culture creates tremendous pressure on both students and parents. In Hong Kong it is common for parents to send their children to two kindergartens with the hope that their children can absorb more information than their peers who attend one school only. Driven by the fear of falling behind, hiring private tutors or sending their children to after-school programs by parents are also prevalent. As a remedy, Hong Kong education reformers devoted tremendous efforts to alleviating the competitive, exam-oriented culture. Beyond conventional exams, Hong Kong education reformers had explored alternate assessment models. The goal is no longer achieving high test scores only, but also the acquisition of general and holistic competencies for work and life. Simply put, the focus of Hong Kong education had shifted **from performance to competence** (Jones & Moore, 1995; Tan, 2018; Tsatsaroni & Evans, 2014). Since the reform, the learning process has become more enjoyable, and the learning objectives are now more diverse.

The analytical result based on the PISA data does not suggest that there is a common tread among the important predictors in Singapore. The reason for Singapore's excellent test performance is multi-faceted and thus awaits further investigation; nonetheless, one plausible explanation might be found in her culture, which emphasizes status, collectivism, stability, and respect for authority or tradition. Thus, critics charge that this orientation downplays individualism and avoids uncertainty by promoting conformity. Singaporean education is highly focused on academic and career development, rather than comprehensive personal growth. Gaining entrance to top-tier universities and landing high-end careers after graduation are of the utmost importance in Singapore's education system. Parentocracy is a well-known term associated with Singapore, where one's educational goals are exclusively oriented toward fulfilling the wishes of his or her parents, and the quality of one's education is largely conditional upon the wealth of one's parents (Tan, 2017).

A recurring pattern was discovered in the Japanese sample. The most important predictors are related to the frequency of using technology at school. This phenomenon could be explained by the fact that Japan is a technologically advanced nation and thus learners tend to fully utilize educational technology.

Like the Singaporean sample, the US sample does not show a clear common theme. Nonetheless, researchers contend that American education has strengths in promoting creativity, de-emphasizing rote memorization, developing higher-order thinking, championing inclusive education, meeting diverse needs, and listening to student voices.