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TYPES OF QUALITY AND EQUAL SCIENCE EDUCATION SYSTEMS AND THE DEVELOPMENT OF EQUALITY IN EDUCATION

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Abstract. *Some education systems have both quality and equality. They have achieved educational equity. This study aimed to uncover the practical wisdom of such systems in developing educational equality. A quantitative research design was used. Family capital and science achievement were the variables analyzed. They were secondary data collected by the 2018 PISA test. PISA surveyed students' family capital with questionnaires and measured students' science achievement with cognitive items. Six education systems with quality but low equality comprised the control group. Its sample size ranged from 4656 to 8312. The experiment group included nine quality and equal education systems, with sample sizes ranging from 3766 to 21490. The relative error and conditional probability were calculated to determine educational equality. Rawls' difference principle was used as a theoretical perspective. The findings showed that quality and equal education systems had three types: equal-start, equal-improvement, and egalitarian. The primary measure to improve equality in education is to ensure educational benefits for students in the bottom quartile of family capital. The development of educational equality was accompanied by a sustained reduction in the achievement gap between the disadvantaged and the advantaged. Implications for educational practice are discussed.*

Keywords: *disadvantaged students, educational equity, equality in education, inequality in education, science education*

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Introduction

Science education needs to be more egalitarian to address anti-intellectualism, gender discrimination, and globalization effectively. The conviction that science is a theoretical system for explaining nature is not unbreakable. Anti-science happens all over the world (Thorp, 2019). Every anti-science adult means there was a minor who wandered out of science in the past. As a result of academic failure, many disadvantaged students do not believe that science is relevant to them (Next Generation Science Standards, 2013, p. 29). But the responsibility does not lie with them (McGee & Martin, 2011). Traditionally, the education system has tended to ignore the potential of disadvantaged students (such as immigrants, people of color, and children from low-income families) to learn science (Next Generation Science Standards, 2013, p. 26). Sadly, disadvantaged students seem to accept this identity (Kang, 2022). Only by significantly raising the academic achievement of disadvantaged groups in science can the number of pessimists and even opponents of science in our future society be reduced. Science education also neglects to be fair to women (Russell, 2020; Ten Hagen et al., 2022). If this situation continues, it will be difficult for science and the scientific community to avoid its adverse effects (Next Generation Science Standards, 2013, pp. 26-28; Russell, 2020). Furthermore, the accelerated process of globalization has led to a greater demand for highly skilled labor in society. When society has reached its limits in tapping the human resources of its advantaged groups, it has to turn to train disadvantaged groups to become skilled STEM laborers (Next Generation Science Standards, 2013, p. 26; Philip & Azevedo, 2017).

Ethics demands science education to increase equality. Science education is designed according to the stereotype of serving the academic elite (McGee & Martin, 2011; McNutt, 2020). Even the science museum, a place for science education outside of school, reflects the cultural practices of the middle class (Feinstein, 2017). As a result, science education is one of the

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causes of the growing inequality gap between people (McNutt, 2020). Some science education systems are "amblyopic" and do not see disadvantaged students. In such a system, education breaks away from its goal of serving all students and becomes subordinate to efficiency. Science education that is "indifferent to disadvantaged students" sets the stage for academic failure and discrimination. Even if we attribute the inequality in science education to the past, we cannot deny that the time has come to address it (Philip & Azevedo, 2017).

Inequality in science education extinguishes capital-disadvantaged students' hopes of success. In the United States, blacks, indigenous, and people of color are disadvantaged groups (BIPOCs, McNutt, 2020). In China, they are farmers and people who have migrated to the cities to work as casual laborers. Children with inferior and superior family capital typically live in different communities and attend diverse schools, as if fated to follow different life paths (Barabino, 2020). The lack of interest in science is the rebellion of disadvantaged students against an unequal education. There is a growing voice in the science community that the time has come for science education to change its systematic discrimination against capital-disadvantaged students (Barabino, 2020; McNutt, 2020; Next Generation Science Standards, 2013, pp. 25-29; Russell, 2020; Thorp, 2019). In the United States, some science teachers have changed their teaching practices. They have advanced educational equality by integrating science practice with the culture of people of color (Kang, 2022; Shea & Sandoval, 2020). It reflects an improved climate of educational equality on a small scale (in one disadvantaged school or several poor communities). Equality in science education means a lot to individuals and society. Only when science education is equal will disadvantaged students give up slacking off. It is then that academic success will not be the exclusive honor of capital-advantaged students.

Literature Review

Educational equity and social justice

The notion of equity is the product of the concept of justice. Justice is a pluralistic concept in political philosophy, and the utilitarian, liberal, and neoliberal views of justice impact people's opinions on educational equity. A person with a utilitarian view of justice believes that maximizing educational productivity is educational equity (L. C. Li & Wang, 2014). A liberal justice advocate believes that educational equity means the most disadvantaged students benefit the most (Rawls, 2005, p. 80, first published in 1971). A neo-liberal justice advocate believes that free competition between schools and students' free choice of schools is educational equity (Bifulco & Ladd, 2006). People live together, so diverse views of educational equity coexist and are reflected as a social reality. In Estonia, for example, the nation's implementation of free education and the allocation of financial subsidies to the poorest students is what liberals see as fair (Lees, 2016). The country also opens private schools, which account for 10% of the total schools, and allows students to receive paid education (Lees, 2016), which is equity in the eyes of neo-liberalism. China's pursuit of high performance in science education has set a group of high-quality schools apart from the competition. Mainland China was the only education system where students scored at level four in science on the 2018 Program for International Student Assessment (PISA) test. It outperformed second-placed Singapore in science by 39 points (Schleicher, 2019). From a utilitarian perspective, this is educational equity. In recent years, China has allocated central financial funds to fill the gap in rural education funds in various provinces (State Council, 2012). The purpose of this measure is to compensate capital-disadvantaged students. It reflects a liberal view of justice and suggests that Chinese society has changed its monolithic utilitarian perspective on the issue of educational equity. In summary, the notion of equity stems from the concept of justice, and multiple understandings of justice can coexist and influence societal and individual beliefs about educational equity.

Meeting quality and equality in education is equity

Equality is the basis of equity. Equality is a collective and objective concept, while equity is an individual and subjective concept (Volckmar, 2019). Equality is a quantifiable, rational judgment that implies equal treatment for all (Clarke, 2014; Volckmar, 2019). Educators follow two routes to refine the definition of equality. One is to define three types of equality from the perspective of political philosophy. Equality of opportunity refers to the equal rights granted by law to everyone to access primary, secondary, and higher education (Espinoza, 2007). "Equality on average across social groups" refers to the balanced distribution of educational resources among different social groups (Espinoza, 2007; Volckmar, 2019). "Equality for all" means that each person receives equal educational resources (Carlson, 1983). Thus, equal distribution of educational resources for all students (e.g., the same amount

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of money per student for education) is equality for all (Allbright et al., 2019; L. C. Li & Wang, 2014). The definition of equality from a political philosophy perspective has a distinctly equal distribution character. It emphasizes that people are treated identically when accessing educational opportunities and resources. The second is to define three types of equality based on a person's school experience. These include equality of opportunity, equality of process, and equality of outcome. The nation has enacted laws or educational policies to decrease gaps among people in terms of educational opportunities, curriculum learning, and learning outcomes. The definition of equality of opportunity is similar to the previous one. It is educational opportunity equality for students from low-income families to attend the same school as advantaged students, as well as for students of different races and ethnicities to enter the same school without social segregation (Dayton & Dupre, 2004). The teachers' love and guidance for students do not vary according to their performance, family background, race, or ethnicity, which is the equality of the educational process (OECD, 2018, p. 9; Savage, 2013). Students achieve similar academic results regardless of gender, family capital, race, or ethnicity, indicating equality of educational outcomes (Zhao et al., 2012). The public can only perceive equity based on equality. In any case, there is no educational equity when the interests of the weak are compromised by severe inequality. For example, the lack of educational resources in schools, which makes students drop out or perform poorly, is an example of educational inequity caused by educational inequality (Castano et al., 2019; Cuesta & Madrigal, 2014; Gewirtz, 1998; M. Li et al., 2022).

There may not necessarily be educational equity even with educational equality, for example, in contexts where all children receive poor-quality teaching. Policies that aim for equality can sometimes result in waste or resources that cannot meet the needs (Allbright et al., 2019). Scholars refer to this as the narrowness of equality (Rizvi & Lingard, 2010, p. 156). This condition can harm quality. The No Child Left Behind Act reflects a policy drift in the United States: a shift from equality to quality (Griffen, 2022). The reason for this shift is that economists believe that educational inequality can only be addressed by improving the quality of teaching (Griffen, 2022). Quality is a subordinate concept of educational effectiveness. Quality means that teachers teach effectively. It is difficult to have quality teaching when science teachers lack scientific knowledge and are afraid to teach science (Lamanauskas, 2022). It has an expanded connotation when quality is used as a subordinate concept to educational equity. The teaching is also of low quality when teachers only consider the needs of some students, leading to resistance from others (Martin, 2019; Webb & Radcliffe, 2016). Student performance in standardized tests is often viewed as a primary quality indicator (Gewirtz et al., 2021). Low-quality teaching is not in the interests of anyone and therefore is not equitable. Quality is, therefore, also the basis of equity. Equality and quality depend on each other to become educational equity.

Educational practice of balancing equality and quality

The difficulty of education practice is that equality and quality are often in conflict. Under the PISA shock, Australia publishes school results through the Myschool website to motivate weak schools to improve the quality of teaching (Loughland & Sriprakash, 2016). Finland and Sweden enhance school effectiveness by strengthening competition (Varjo et al., 2018). The Sage School District in California provides some schools with more material and human resources than others (Allbright et al., 2019). These measures favor quality but can undermine equality. There are winners and losers in the competition. The winning schools can raise the price of estates in neighboring communities and segregate disadvantaged students (Schleicher, 2019). That worsens educational equality. Currently, between the elitist tradition of education and equality, there is a voice that regards equality as the core value of educational equity (Nachbauer & Kyriakides, 2020; Van Damme & Bellens, 2017). However, it is worth being wary that practices conducive to equality may harm the quality of education. Japan and Korea have implemented teacher mobility systems that favor equality in education (Fu et al., 2015; OECD, 2018, p. 41). However, this system is almost exclusive to Japan and Korea. China praises its value of promoting equality but does not draw on this system. It is because the instability of school human resources may be detrimental to its teaching quality. The practice of educational equity thus requires balancing equality and quality. It means neither harming quality for the sake of equality nor harming equality for the sake of quality. Estonia, for example, has a comprehensive school system and provides financial assistance to disadvantaged students to guarantee equality in education (Lees, 2016). At the same time, its curricula and examinations are of a high standard to reinforce the quality of education (Tucker, 2015). Equality and quality are balanced, rather than sacrificing one for the other, thus advancing equity in education. At this point, the academic performance of both disadvantaged and advantaged students improves, and the disadvantaged students' performance improves even more.

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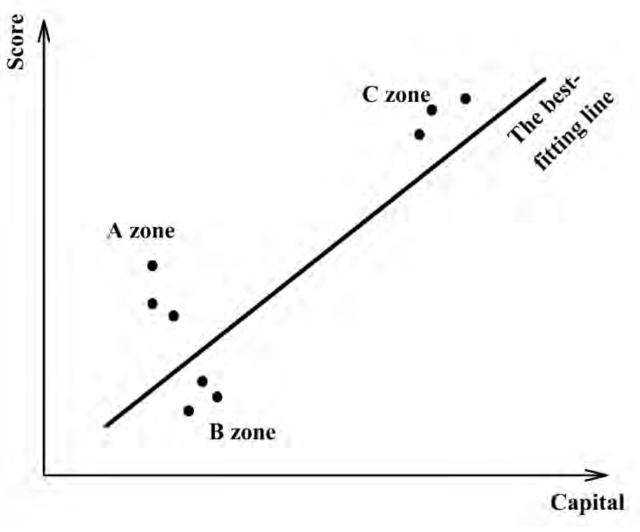
Research Problem

Assessing equality in science education is difficult. The regression analysis has long been a typical data analysis method of determining equality in education (Nachbauer & Kyriakides, 2020). It uses a coefficient of determination (*R*-squared) to indicate the strength of the association between family capital and achievement. In the 2018 PISA test, education systems with a coefficient of determination of less than 10% were considered equal, while greater than 15% indicated low equality (OECD, 2019, p. 60). However, there is a logical flaw in judging educational equality by the *R*-squared.

There is a logical defect in using a decreasing coefficient of determination as an increase in educational equality. As shown in Figure 1, the oblique line is the best-fitting line. The left side of the horizontal axis is the area of capital disadvantage, and the right is the advantaged area. When all data points (each representing one student) fall on the fitted line, capital explains 100% of the variance of scores according to the principle of ordinary least squares (Lewis-Beck, 1980, p. 22).

Figure 1
Educational Equality Interpreted by the Coefficient of Determination



As shown in Figure 1, students moving from the fitting line to zones A or B can increase the unexplained deviation attributed to random error and reduce the strength of the capital-score connection (Mendenhall et al., 2013, p. 498; Vittinghoff et al., 2012, p. 42). If one were to take the perspective of *R*-squared, one would argue that educational equality increases. However, there is a logical fallacy here. Only migration to Zone A increases equality in education as the achievement of capital-disadvantaged students rises. On the other hand, migration to Zone B decreases educational equality because the academic performance of capital-disadvantaged students decreases. As shown in Figure 1, the migration of students from the fitting line to area C can also reduce the strength of the capital-score connection. However, as the achievement gap between students with superior and inferior family capital increases, it is also an example of reduced educational equality. In conclusion, there are logical flaws in using a decreasing *R*-squared as evidence of increased educational equality.

There is a logical defect in using an increasing coefficient of determination as educational equality reduction. For example, when students move from Zone B back to the fitting line, the economically disadvantaged students narrow the achievement gap with the advantaged students. Educational equality is increasing rather than decreasing. In addition, several scenarios can cause biased estimates of the coefficient of determination. These include that residuals do not comply with independence, normality, and homoscedasticity; multicollinearity among predictors; and missing key predictors from the regression equation (George & Mallery, 2020, pp. 193-220; Lewis-Beck, 1980). Given the shortcomings of the coefficient of determination, it is necessary to propose new data analysis methods to analyze educational equality issues.

https://doi.org/10.33225/jbse/23.22.439

Research Focus

The study focused on assessing equality in science education. According to the regression analysis, Finland does not rank ideal in science education equality (R^2 = .105, see Table II.B1.2.4, OECD, 2020a). If this is the case, it would suggest that the "quality" pole of education has oppressed the "equality" pole, resulting in a regression in equality. For Finland, it is time to consider how to reconcile quality and equality. For other countries, it matters to find new learning objectives to guide the development of their science education.

The study focused on the types of equitable science education systems. Quality and equality are educational equity. Equity in science education has been achieved in some developed countries or economies. Traditionally, science education has been studied using variable-centered data analysis methods such as regression analysis. This approach sees the connections between variables but not the "people." That makes events a black box. People know that there is an equitable science education system but do not know how it is formed. To analyze the types of equality in equity science education systems with a new person-centered data analysis method is to expose the structure of the "black box."

Theoretical Perspective, Research Aim, and Research Questions

The difference principle is a theoretical perspective for analyzing issues of educational equity. Equality and justice are the core concepts in understanding the difference principle. Rawls (2005) used the example of "dividing a cake" to demonstrate how egalitarian distribution can be accomplished (p. 85). Even under a system of equal distribution of educational resources, advantaged students still gradually widen the performance gap between them and disadvantaged students. Rawls (2005) called this phenomenon the negative marginal contribution of the advantaged group to the disadvantaged group (p. 79). For the sake of justice, the education system should avoid this phenomenon. Rawls has proposed the difference principle to address this issue. This principle requires society to take measures to benefit the least advantaged groups the greatest (Rawls, 2005, p. 83). This study believed that the difference principle guided the practice of science education systems in raising the achievement of disadvantaged students.

This study aimed to open the black box of an equitable science education system. It was a two-step process. The first step was to know the pathway from low equality to equality; the second was to find out how equality is improved. Quality and equality are the reform goals of science education in all countries. The significance of opening the "black box" is to point out the way for science education in various countries to reach its goal.

The research questions were:

1. What educational outcomes have students with different family capital achieved in a quality but low-equality science education system?
2. What types of equality were present in equitable science education systems?
3. What were the differences in the probability of academic success in science between various student groups in the above two kinds of science education systems?

The answers to the above questions give clues to the path from low equality to equality and the continuous improvement of equality.

Research Methodology

General Background

The documentary method was used. Data were collected by the PISA 2018 project team. The PISA test concerns the well-being of students. It surveyed secondary school students' family capital through questionnaires while measuring their reading, mathematics, and science performance with cognitive items. Student achievement reflects the quality of a school and can also indicate whether educational policies support the improvement of school effectiveness (OECD, 2020b, p. 39). From the fourth test in 2009 to the seventh test in 2018, the PISA project team has released several volumes of reports after each test. The analytical contents of volumes one and two are fixed. Volume one analyzes the quality of education in each country or economy based on student achievement. The second volume assesses the equity of education systems based on the connection between student family

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capital and achievement. Participants were anonymized, and their family capital and achievement were recorded in the student data set (OECD, 2020c).

Six science education systems with quality but low equality appeared in the 2018 PISA test. They were the control group, and their *R*-squared ranges between .159 and .201 (see Table II.B1.2.4, OECD, 2020a). Analyzing the educational outcomes of capital-disadvantaged and advantaged students in such systems opened the systems' black box. Nine systems with equality and quality in science education emerged from the 2018 PISA test. The strength of their family capital and science achievement connections (*R*-squared) ranged from .016 to .10 (see Table II.B1.2.4, OECD, 2020a). It provided a rich sample pool of equitable science education systems. The significant variation in *R*-squared predicted that students in these systems received different types of equality. The discovery of various forms of equity in science education gave an idea of how equality has increased. These nine education systems were the experimental group. Comparing the equality status of the control group with that of the experimental group showed the path from low equality to equality.

This study used the achievement matrix to assess educational equality. That is a person-centered data analysis method that focuses on "Whose educational benefits are guaranteed?" The indicator used in the regression analysis to evaluate equality is the coefficient of determination, whereas the statistics used in the achievement matrix are relative error and conditional probability.

Disadvantaged, most disadvantaged, and successful students had different meanings in the following text. This study defined groups with family capital below the median as "disadvantaged students." The opposite was true for "advantaged students." Groups with family capital below the lower quartile were the most disadvantaged students, while students whose family capital was above the upper quartile were the most advantaged. Students with scores above the upper quartile were called "success students." These students are the primary source of the nation's future STEM workforce (Tai et al., 2006).

The Achievement Matrix

The achievement matrix used family capital as a row variable and academic achievement as a column variable. Students were divided into four levels according to their family capital. Students in each family capital level were then divided into four grades according to academic achievement to obtain the number of students in each element.

$$\text{Achievement matrix} = \begin{vmatrix} n_{11} & n_{12} & n_{13} & n_{14} \\ n_{21} & n_{22} & n_{23} & n_{24} \\ n_{31} & n_{32} & n_{33} & n_{34} \\ n_{41} & n_{42} & n_{43} & n_{44} \end{vmatrix}$$

Where n_{11} represented the number of students whose family capital and academic performance were both below the 25% percentage level, n_{12} represented the number of students whose family capital was below the 25% percentage level and whose academic performance was between the 25% and 50% percentage levels, and so on with the other elements. The upper eight elements represented disadvantaged students, whereas the bottom eight represented advantaged ones.

The achievement matrix analysis technique is designed based on the concept of a veil of ignorance (Rawls, 2005, pp. 136-141). Behind a veil of ignorance, nature does not perceive any difference between high and low family capital. Students at a particular family capital level are assigned equally to the four cells in the row of that family capital level in the achievement matrix. Setting the total number of students at *N* gives an expectation of .0625*N* for each element.

The Relative Error

This study defined students on the diagonal as regular students, reflecting the degree of consistency between family capital and achievement. Elements n_{11} and n_{22} also represented disadvantaged students. The other identity for individuals in elements n_{33} and n_{44} was that of advantaged students. The relative error for regular students was the absolute value of the actual number of regular students minus the expected number, divided by the expected number. Since inequality existed in every education system, this difference (the numerator part of the relative error formula) was always positive.

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In the case of the most disadvantaged students, those in elements n_{12}, n_{13}, and n_{14} achieved academic achievement grades that exceeded their family capital levels. The same was true for students in n_{23} and n_{24}. The area in which n_{11}, n_{21}, and n_{22} were located was in the low-score area. If education were completely unequal, disadvantaged students would be grouped in this partition. The elements n_{12}, n_{13}, n_{14}, n_{23}, and n_{24} represented students who migrated from the low-score division. The more students in these five elements, the better the educational benefits for disadvantaged students. The relative error for disadvantaged students was the absolute value of the actual value of these five elements minus their expected value, divided by the expected value. This difference has always been a negative number. Due to educational inequality, the actual number of students in elements n_{12}, n_{13}, n_{14}, n_{23}, and n_{24} was always less than the expected number.

For advantaged students, elements n_{33}, n_{34}, and n_{44} were located in the high-score area. If education were completely unequal, they would all be in this section. Elements n_{31}, n_{32}, n_{41}, n_{42}, and n_{43} represented students who migrated from the high-score division. The more students there were in these five elements, the smaller the performance gap between them and the disadvantaged. The relative error for advantaged students was the absolute value of the difference between the actual value of these five elements and their expected value, divided by the expected value. This difference was always negative due to educational inequality.

The Conditional Probability

Students with various family capital had different odds of academic success in science. The probability of achieving level 4 in science when family capital was at level 1 (P [score = 4 | capital = 1]) represented the friendliness of science education to the most disadvantaged students. Similarly, P [score = 4 | capital = 4] demonstrated how science education could benefit the most advantaged students. The closer P [score = 4 | capital = 4] and P [score = 4 | capital = 1] were, the better the educational equality.

Person-centered

The achievement matrix sees people. Each student had a fixed position in the matrix based on their family capital and scores. Relative errors and conditional probabilities measure educational outcomes. For example, the decreasing relative errors for disadvantaged and advantaged students indicated that the achievement gap had narrowed. Conditional probabilities determined the degree of educational equality by analyzing the difference in the chances of academic success between disadvantaged and advantaged students.

Relative error is the primary indicator of educational equality. It was calculated with all the information in the achievement matrix. The conditional probability was only related to the elements of the fourth column of the matrix. The conditional probability is a secondary indicator of education equality, and its significance is to explain the original family capital structure of the country's future STEM workforce.

Sample

The experimental group samples were from quality and equal education systems. Based on the PISA criteria, a score above the average of OECD countries was considered good quality, and a coefficient of determination below 10% was considered equality in education (OECD, 2019, p. 60). In the 2018 test, Australia, Canada, Estonia, Hong Kong (China), Japan, Korea, Latvia, Macao (China), and Norway met the criteria (see Table II.B1.2.4, OECD, 2020a; Schleicher, 2019). These nine systems are the objective references for science education. PISA has defined a coefficient of determination of 15% or more as low equality in education (OECD, 2019, p. 60). The control group samples were from six science education systems with good quality but lower equality. They were Belgium, the Czech Republic, France, Germany, Portugal, and Switzerland (see Table II.B1.2.4, OECD, 2020a; Schleicher, 2019).

Measurement and Procedures

The achievement matrix was created using two variables: family capital and science scores. Science scores were divided into eight levels, from below 261 to above 708; students achieving a score of 633.33 or above were called top performers in science (OECD, 2019, p. 152; Schleicher, 2019). The PISA test has used family assets to represent economic capital, parents' occupational status to describe social capital, and parents' educational status to indicate

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cultural capital to obtain the student's family capital (OECD, 2020d). This variable was standardized and named an index of economic, social, and cultural status (abbreviated as ESCS; OECD, 2020d). The student data set recorded the ESCS and science scores of the participants (OECD, 2020c). The ESCS had missing values, and the score had no missing values. Records with missing values were removed, then the analysis procedure was performed.

The analysis process was divided into two steps. The first was to calculate the relative error based on the achievement matrix. Descriptive statistics were performed using SPSS 25 to obtain three quartile values for ESCS and scores. Then the data was saved in spreadsheet format. The SUMPRODUCT() function in the spreadsheet returned the number of students in elements n_{11}~n_{44}. Three types of relative errors were calculated according to the previous definition. The second step was to derive the joint probability based on the achievement matrix and then calculate the conditional probability. There were sixteen conditional probabilities in total. This study was concerned with four conditional probabilities representing academic success in science. The probability that ESCS = 1 occurred simultaneously with score = 4 was calculated from the value of element n_{14}. The marginal probability of ESCS = 1 was .25. P [score = 4 | ESCS = 1] was obtained by dividing the joint probability by the marginal probability. The process for calculating the other three conditional probabilities was the same. P [score = 4 | ESCS = 1] and P [score = 4 | ESCS = 2] are significant for society. They indicate whether the nation's intention to train disadvantaged groups to become skilled STEM workers is likely to be realized.

Data Analysis

As shown in Table 1, the sample has good data quality. The percentage of missing data ranged from .24% to 14.58%. Samples with more than 5% missing data were Germany (14.58%), Australia (10.06%), Canada (5.13%), and Portugal (5.06%). Samples with no more than 15% missing data do not cause significant bias in the analysis results (Creswell, 2014, p. 202). Top performers and standard deviations were calculated using the original dataset. There were four samples where top performers accounted for more than 10% of the total. They were Japan, Macao (China), Estonia, and Korea. These four countries or economies occupied the top four positions in the PISA science performance ranking among the fifteen samples (Schleicher, 2019). The quartiles in Table 1 are calculated after deleting the missing values.

Table 1
Sample Size of Participating Countries or Economies and Descriptive Statistics for ESCS and Science Scores

Countries/ economics	Sample size		Percentiles_ESCS			Percentiles_Score			Top per-formers %	*SD*
	Valid	Missing	25	50	75	25	50	75		
Belgium	8312	163	-.562	.188	.842	436.8	511.2	572.5	7.0	93.6
Czech Republic	6911	108	-.746	-.162	.626	447.2	516.5	583.1	9.5	92.8
France	6176	132	-.696	-.025	.629	416.8	492.3	557.6	5.1	94.7
Germany	4656	795	-.798	-.036	.719	444.2	519.7	586.3	8.9	98.6
Portugal	5632	300	-1.27	-.381	.671	429.1	495.2	557.2	4.0	86.7
Switzerland	5705	117	-.597	.048	.743	430.3	497.3	562.4	6.2	90.6
Australia	12813	1460	-.302	.441	1.03	435.5	509.1	575.1	8.3	95.2
Canada	21490	1163	-.192	.479	.996	447.7	512.4	575.5	8.0	89.5
Estonia	5202	114	-.502	.144	.744	473.3	532.7	587.2	11.2	82.6
Hong Kong (China)	5839	198	-1.24	-.579	.212	469.8	527.1	575.6	5.5	78.9
Japan	6055	54	-.620	-.071	.437	468.1	534.7	593.9	11.8	87.5
Korea	6626	24	-.445	.156	.651	458.7	527.3	586.9	10.6	91.9
Latvia	5187	116	-.666	.056	.659	432.3	486.9	540.5	2.0	77.1
Macao (China)	3766	9	-1.17	-.571	.162	494.2	548.6	598.6	11.6	77.3
Norway	5612	201	.028	.666	1.11	428.1	496.1	558.9	5.3	93.2

Note. SD = the standard deviation of science scores.

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Research Results

Science Education Systems with Low Equality

Six samples from the control group fell into this category. Table 2 gives information on the three types of relative errors for the fifteen samples. The characteristics of the low-equality education system were that the relative error for advantaged and disadvantaged students exceeded 19%, and the relative error for regular students approached or exceeded 50%. The reason was that the values of elements n_{11} and n_{44} were particularly large. The scores of the most disadvantaged students concentrated in the region of the lower quartile, and the scores of the most advantaged students fell into the upper quartile area. In the French sample, for example, $n_{11} = 752$ and $n_{44} = 768$. The value of element n_{11} was 1.95 times its expected value, and for element n_{44}, this ratio was 1.99. The amounts of elements n_{22} and n_{33} were close to their expected values. The values were 1.22 times and 1.21 times the expected values, respectively. Portugal, Switzerland, and Germany decreased three types of relative errors. In Portugal, for example, the values of elements n_{11}, n_{22}, n_{33}, and n_{44} were 1.71, 1.17, 1.16, and 1.89 times the expected values, respectively. The decrease in the number of students in elements n_{11}, n_{22}, n_{33}, and n_{44}, especially in n_{11}, reduced educational inequality.

Table 2
Four Types of Equality in Quality Science Education Systems

Types	Countries/ economics	R^2 %	*N*	Disadvantaged students		Advantaged students		Regular students	
				n_1	Relative error %	n_2	Relative error %	n_3	Relative error %
Low-equality	France	20.1	6176	1417	26.58	1419	26.48	2461	59.39
	Belgium	20.0	8312	1964	24.39	1930	25.69	3228	55.34
	Czech Republic	16.9	6911	1627	24.67	1637	24.20	2665	54.25
	Germany	18.6	4656	1143	21.44	1145	21.31	1740	49.48
	Switzerland	16.3	5705	1428	19.91	1400	21.47	2092	46.68
	Portugal	15.9	5632	1414	19.66	1395	20.74	2086	48.15
Equal-start	Australia	10.0	12813	3304	17.48	3284	17.98	4422	38.06
	Norway	8.9	5612	1498	14.58	1454	17.09	1878	33.86
Equal improvement	Estonia	7.2	5202	1376	15.36	1377	15.29	1697	30.49
	Latvia	8.4	5187	1388	14.37	1374	15.23	1683	29.79
	Canada	6.4	21490	5780	13.93	5665	15.64	7001	30.31
	Korea	8.0	6626	1779	14.08	1763	14.86	2173	31.18
	Japan	7.7	6055	1650	12.80	1619	14.44	1924	27.10
Egalitarian	Hong Kong (China)	5.7	5839	1650	9.58	1621	11.61	1836	25.77
	Macao (China)	1.6	3766	1132	3.81	1117	4.92	1043	10.78

Note. R-squared is the explanatory power of ESCS on students' science scores in that country or economy, as documented in the PISA 2018 results (see Table II.B1.2.4, OECD, 2020a). *N* is the total number of subjects who took the PISA 2018 test without missing ESCS values.

Elements n_{11} and n_{22} were in the low-score area, and n_{33} and n_{44} were in the high-score area. Therefore, a reduction in the relative errors for disadvantaged and advantaged students would usually reduce the number of students on the main diagonal and thus reduce the relative error for the regular student. However, an anomaly was found when comparing the Swiss and Portuguese samples. Portugal had lower relative errors for disadvantaged and advantaged students but a higher rather than lower relative error for regular students. That was due to the migration of students from element n_{34} to n_{33}. In the Portuguese sample, the value of n_{34} was only .989 times the expected value (in general, the value of this element was significantly higher than the expected value).

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Three Types of Equality in Equitable Science Education Systems

The equal-start system was named because the education system started to help disadvantaged students instead of just chanting slogans. The significant reduction in the relative error for the regular student indicated a rapid decline in the numbers in elements n_{11} and n_{44}. In Australia, for example, the values for n_{11} and n_{44} were 1.61 and 1.64 times the expected values, respectively.

The equal-improvement system was named because it further reduced the achievement gap between disadvantaged and advantaged students compared to the equal-start system. There were two ways to improve equality in the education system. Estonia and Canada each represented one. In Estonia, disadvantaged students moved to the high-score area, and advantaged students moved to the low-score zone in a balanced way. This approach led to a minor difference in the relative error for disadvantaged and advantaged students. In Canada, the number of disadvantaged students moving to the high-score area was higher than the number of advantaged students moving to the low-score area. This practice resulted in a lower relative error for disadvantaged students than for advantaged students.

The egalitarian system got its name because it achieved a high degree of educational equality that would not have been possible without the emphasis on equality. Such education systems paid much more attention to the educational benefits of disadvantaged students. In the Hong Kong (China) sample, element n_{11} was only 1.38 times its expected value. It was further reduced to 1.18 times in the Macao (China) sample. It led to a rapid increase in the number of disadvantaged students achieving science achievement levels that exceeded their family capital levels. However, there was also a further increase in advantaged students migrating from high to low-score areas in this education system.

The Probability of Academic Success in Science for Students with Different Family Capital

Table 3 shows the information on successful students in the science domain. It focused only on the four elements of the fourth column of the achievement matrix. Therefore, the analysis of equality in science education from Table 3 is a partial and one-sided perspective. But it can complement the information in Table 2. The transition from a low to a high equality type demonstrated a sustained increase in the probability of disadvantaged students' success in science. In the low-equality type education system, the most advantaged students were five or more times more likely to succeed in science than the most disadvantaged students. In the Czech Republic, for example, only 6.48% of the most disadvantaged students scored in the upper quartile region, while nearly half of the most advantaged students' scores were in the upper quartile region. Compared to the low-equality education system, the equal-start education system had an increase in P_1 and a decrease in P_4. It reduced the gap in academic success between the most disadvantaged and the most advantaged groups. In the equal-improvement system, the P_1 value increased consistently and raised equality compared to the equal-start system. Japan was special. Although its P_1 value was comparable to the equal-start system, its P_2 value was higher than the rest of the sample in the equal-improvement education system. In the equal-improvement type system, there were approximately six advantaged students and three disadvantaged students for every nine successful students. In an egalitarian system, P_1 and P_2 increased while P_3 decreased. The gap between P_1, P_2, P_3, and P_4 was further reduced.

Table 3
The Conditional Probability of Success in Science for Secondary School Students with Different Family Capital across Countries/ Economics

Types	Countries/ economics	Conditional probabilities				Ratios of conditional probabilities		
		P1	P2	P3	P4	P4/P1	P3/P1	P2/P1
Low-equality	Czech Republic	.0648	.1700	.2888	.4756	7.340	4.457	2.623
	France	.0704	.1524	.2796	.4976	7.068	3.972	2.165
	Belgium	.0844	.1676	.2776	.4708	5.578	3.289	1.986
	Germany	.0860	.1856	.2724	.4560	5.302	3.167	2.158
	Switzerland	.0916	.1872	.2700	.4508	4.921	2.948	2.044
	Portugal	.0936	.1876	.2472	.4716	5.038	2.641	2.004

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Types	Countries/ economics	Conditional probabilities				Ratios of conditional probabilities		
		P1	P2	P3	P4	P4/P1	P3/P1	P2/P1
Equal-start	Australia	.1240	.1832	.2820	.4108	3.313	2.274	1.477
	Norway	.1160	.2016	.2944	.3876	3.341	2.538	1.738
Equal improvement	Japan	.1104	.2160	.3000	.3732	3.380	2.717	1.957
	Estonia	.1392	.1800	.2736	.4068	2.922	1.966	1.293
	Latvia	.1372	.1868	.2892	.3864	2.816	2.108	1.362
	Canada	.1368	.1916	.2936	.3779	2.762	2.146	1.401
	Korea	.1372	.1976	.2776	.3876	2.825	2.023	1.440
Egalitarian	Hong Kong (China)	.1632	.2144	.2376	.3843	2.355	1.456	1.313
	Macao (China)	.1912	.2476	.2348	.3260	1.705	1.228	1.295

Note. P_1 = P [score = 4 | ESCS = 1], P_2 = P [score = 4 | ESCS = 2], P_3 = P [score = 4 | ESCS = 3], P_4 = P [score = 4 | ESCS = 4].

Discussion

The relative error is an indicator of equality in education. The coefficient of determination deals with the association between variables (Nachbauer & Kyriakides, 2020; OECD, 2019). In contrast, the relative error is an indicator related to the person. A decrease in the relative error for disadvantaged students meant that more students migrated from lower to higher-scoring areas. A reduction in relative error for advantaged students implied the opposite migration process. Thus, a decrease in the relative errors for advantaged and disadvantaged students indicated the mechanism by which the achievement gap between the two groups of students was reduced. When comparing the Czech Republic with Germany, the coefficient of determination showed that educational inequality was higher in Germany (OECD, 2020a). However, the relative errors for disadvantaged and advantaged students showed that educational inequality was higher in the Czech Republic than in Germany.

The application of relative error is very flexible. For example, society may not consider that the migration of the most disadvantaged students to the n_{12} also represents an increase in educational equality. The score in the region between the lower quartile and the median may not help students' future position in the labor market. In other words, students in elements n_{11} and n_{12} will be engaged in the same work. Only when students migrate to n_{13} and n_{14} can education equality be improved. At this time, the relative error for disadvantaged students can be calculated based on the four elements of n_{13}, n_{14}, n_{23}, and n_{24}. However, this study did not favor omitting n_{12} to calculate the relative error for disadvantaged students. This approach was one-sided because it only looked at the issue of educational equality from the perspective of academic success. It deviated from the core concern of equality, "person." It regarded the struggle and efforts of the most disadvantaged students in element n_{12} as insignificant. On the contrary, this study considered each student in elements n_{12}, n_{13}, and n_{14} as having the same significance and value for educational equality.

Conditional probability is a complementary indicator of equality in education. If equality in education must be assessed from the perspective of academic success, the indicator conditional probability can be used. In addition to being used as an indicator of education equality, it can also be used as an indicator of the national development index. The P_1 values for the low-equality type systems were all less than .1, and the P_4 were all greater than .45. By 2024–2025 (six to seven years following 2018), only one in every eleven to fifteen new STEM workers will come from the most disadvantaged families. In an egalitarian education system, the situation will be much better. In Macao (China), between 2024 and 2025, for every five new STEM workers, approximately two will come from the most advantaged families and about one from each of the other three family capital levels. If disadvantaged students see no hope of achieving upward career mobility through science education, it can lead to many of them slacking off (McNutt, 2020; Next Generation Science Standards, 2013, p. 29). That would be detrimental to the country's high-tech human resource building in a globalized community.

Countries or economies develop educational equity in the competition between equality and quality. Generally, in the contest between them, the elitist tradition of education makes the nation pay much more attention to

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quality than equality (Pitman & Vidovich, 2012). This practice has resulted in a large academic gap between disadvantaged and advantaged students. In the control group, there was a close connection between students' scores and their family capital. Students were gathered in the four elements on the diagonal of the achievement matrix. The most disadvantaged students were less likely to achieve academic achievement grades that exceeded their family capital levels. Rawls (2005) has argued that quality alone does not ensure equity in education (p. 71). He has proposed that education should guarantee the benefits of the most disadvantaged students (Rawls, 2005, p. 80). Estonian secondary education balances equality and quality (Lees, 2016; Tucker, 2015). It has enabled Estonia to achieve equity in science education. A large number of students moved out of the elements on the diagonal, making the relative error for regular students in the Estonian sample about 30% smaller than that in France. The experimental group sample showed that the countries or economies valued equality in education. That was due to the full consideration of the political value of equality in promoting social cohesion.

In the experimental group, the disadvantaged students' performance improved while the gap between them and the advantaged students was reduced. It may be argued that this was unfair to the advantaged students. However, according to Rawls' principle of difference, advantaged students can benefit from improving disadvantaged students' performance. That is because the disadvantaged students' increased achievements prompt advantaged students to adjust their academic expectations and set higher achievement goals (Rawls, 2005, pp. 76-80). Higher goals motivated advantaged students to strive for better achievement. In this way, the academic competition between disadvantaged and advantaged students ensured equality and promoted quality at a higher level. Students in Macao (China), Estonia, Japan, and Korea achieved outstanding science performances in an equal climate. They were examples of "increased equality benefiting both disadvantaged and advantaged students."

Conclusions and Implications

The key measure to improve educational equality was to ensure the educational benefits of the most disadvantaged students. In the low-equality education system, the number of students in element n_{11} reached approximately two times its expected value. In the experimental group, the value gradually decreased to about 1.2 from the equal-start type to the egalitarian type system. In the low-equality system, the number of students in element n_{22} was approximately 1.2 times its expected value. There is not much room for that figure to fall. Thus, Rawls' profound gaze had penetrated the crux of the problem of equality in education half a century earlier. When educational practice aims to ensure the educational benefits of the most disadvantaged students, it can promote educational equality.

The findings exposed the path toward developing equality in a quality science education system. Moving from a low-equality type to an equal-start type system required a substantial reduction in the relative error for the regular student. It implied a rapid decrease in the number of students in elements n_{11} and n_{44} on the main diagonal. This measure mitigated the consistency between family capital and achievement. The path to high equality in an equitable science education system was paved by disadvantaged students continuously narrowing the academic achievement gap with advantaged students. The advantaged students previously held a great achievement advantage over the disadvantaged students. This great advantage is unfair. It is an anomaly that derives from the family capital. Improving equality meant substantially improving the academic performance of disadvantaged students without causing a regression in the performance of advantaged students. That narrowed the huge advantage held by advantaged students without compromising their educational gains. Macao (China), Estonia, Japan, and Korea were examples of such education systems.

There were three types of equitable science education systems, which were the objective reference for science education across countries. The relative errors for disadvantaged and advantaged students in the equal-start system were between 16% and 19%. The two kinds of relative errors between 12% and 16% were equal-improvement type, and those below 12% were egalitarian type. In addition, in quality but low-equality education systems, these relative errors were more than 19%. This study did not analyze countries or economies with a determination coefficient between 10% and 15% in the PISA test. These education systems can be classified as low-equality or equal-start type based on their relative errors.

The study has several implications. First, new indicators have been constructed to assess equality in education. Relative errors make a more precise distinction between levels of equality. Second, since the least advantaged students gather in the lowest-scoring areas, they need external help more urgently than any other group. The education benefits of the most disadvantaged are well guaranteed in quality and equal science education systems. It provides evidence that Rawls' difference principle has guided the practice of developing equality in education systems. Third,

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the reward is substantial for the nation to devote additional financial resources to developing educational equality. Increased equality in education will lead to the emergence of many people with high academic performance among disadvantaged groups. It broadens the source of talent in the field of STEM. The analytical techniques of this study can be applied to a wide range of educational equality issues. It has been suspected that students with lower academic performance receive less teacher guidance. That is an issue of equality in the educational process. It can be examined using student achievement and perceived teacher feedback as the row and column variables of the matrix, respectively.

Limitations and Future Research

The achievement matrix is not applicable for nominal variables. For example, the achievement matrix analysis technique is inappropriate when the researcher is interested in gender equality in science education. The results described three types of equitable science education. It can guide the direction of science education reform across countries but cannot provide specific strategies or educational policy details. Future research should further explore the impact of curriculum and educational policies on the development of science education. As can be seen from Tables 2 and 3, Latvia and Estonia share similar educational equality. However, Estonia's science performance exceeded Latvia's by 43 points. The difference in the quality of science education between the two countries may be due to the science curriculum and examination standards or to the training and preparation of science teachers. The real reasons need to be explored. The findings provided the path from a low-equality system to an equal system and the evolution of equality in equitable science education systems. However, this study cannot answer how to transition from a low-quality to an equity-type education system. Follow-up studies should select appropriate samples for data analysis and domestic education policy analysis. A 4×4 achievement matrix was used in this study. The most disadvantaged students were those with family capital in the bottom quartile. Other studies that define the most disadvantaged students as having less than 12.5% family capital can employ an 8×8 achievement matrix.

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Declaration of Interest

The authors declare no competing interest.

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