MONASH University

Learningtower: Comparative Analysis of PISA 2022 and Historical Data

Shabarish Sai Subramanian
Master of Business Analytics

Guan Ru, Chen
Master of Business Analytics

Report for
ETC5543 Business analytics creative activity, 2024

29 October 2024

MONASH BUSINESS SCHOOL

Department of Econometrics & Business Statistics

(03) 9905 2478
BusEco-Econometrics@monash.edu

ABN: 12 377 614 012

1 Abstract

The 'learningtower' R package, a powerful tool for exploring and analysing data from the 2000–2022 Programme for International Student Assessment (PISA), which is led by the Organisation for Economic Co-operation and Development (OECD). Reading, math, and science ability among 15-year-old pupils is measured as part of the triennial PISA international research, which assesses educational systems around the world. This thorough evaluation shows the efficacy of various educational policies and methods across countries in addition to offering insights on student accomplishment.

The package provides a suite of tools that streamline data curation, visualization, and statistical modeling, empowering researchers to investigate crucial areas of educational research. These include gender disparities, socioeconomic impacts on student performance, and trends over time. Learningtower's user-friendly interface allows academics, policymakers, and educators to readily access and analyze PISA data, enabling them to conduct comprehensive research that informs evidence-based decision-making in education.

However, the package has certain limitations, such as potential data size constraints, inconsistencies in questionnaire design across PISA cycles, and missing data in certain years and countries. Additionally, the exclusion of recent assessments and student data on attitudes, well-being, and learning experiences might limit a more comprehensive view of student performance.

Despite these limitations, the learningtower package remains a valuable tool for educational research. It provides a comprehensive dataset, facilitates cross-country comparisons and longitudinal studies, and enables the exploration of factors influencing student achievement. The package promotes open and repeatable research, fostering collaboration and enhancing the validity of educational analyses. By continuing to be updated with new PISA data and addressing limitations, the learningtower package will remain a crucial resource for understanding and improving global education systems.

2 Introduction and background

PISA

The OECD is a global organization that aims to create better policies for better lives. Its mission is to create policies that promote prosperity, equality, opportunity, and well-being for all(Organization for Economic Cooperation and Development 2021a). PISA is one of OECD's programme for International Student Assessment. PISA assesses 15-year-old students' potential to apply their knowledge and abilities in reading, mathematics, and science to real-world challenges. OECD launched this programme in 1997, it was initially administered in 2000, since the year 2000, it has involved more than 100 countries and economies and has conducted tests of more than 3.7 million students worldwide.(Organization for Economic Cooperation and Development 2021b) The PISA study, conducted every three years, provides comparative statistics on 15-year-old students' performance in mathematics, reading, and science.

Learningtower Package

While the full PISA data is available on the website, it is not readily accessible by user due to downloading and curating data across multiple years of the PISA study could be a time consuming task. Thus the 'learningtower' package was developed by Wang et. al. 2021 to provide quick access to a variety of variables in the OECD PISA data collected over a three-year period from 2000 to 2022 (Wang et al. 2021). This dataset includes information on the PISA test scores in mathematics, reading, and science. Furthermore, these datasets include information on other socioeconomic aspects, as well as information on their school and its facilities, as well as the nations participating in the program.

The learningtower package primarily comprised of three datasets: `student`, `school`, and `countrycode`. The `student` dataset includes results from triennial testing of 15-year-old students throughout the world. This dataset also includes information about their parents' education, family wealth, gender, and presence of computers, internet, vehicles, books, rooms, desks, and other comparable factors. Due to the size limitation on CRAN packages, only a subset of the student data is integrated in the downloaded package, with the full data also downloadable using the `load_student("all)` function. These subsets of the student data, known as the `student_subset_yyyy` (`yyyy` being the specific year of the study) allow uses to quickly load, visualise the trends in the contained data. The `school` dataset includes school weight as well as other information such as school funding distribution, whether the school is private or public, enrollment of boys and girls, school size, and similar other characteristics of interest of different schools these 15-year-olds attend around the world. The `countrycode` dataset includes a mapping of a country/region's ISO code to its full name.

As mentioned ealier, although PISA data is accessible to the general public via the OECD website, researchers and analysts may encounter considerable difficulties due to the datasets' intricate structure and variety of forms. Effective analysis may be hampered by these intricacies, making it challenging to glean significant insights from the abundance of available data. By combining extensive datasets, the learningtower package tackles these issues head-on. Learningtower package enables comprehensive cross-sectional and longitudinal research through a methodical process of data cleansing, standardisation, and preparation, making it easy for users to traverse the complexities of educational data.

Moreover, the addition of the 2022 dataset enhances the package's relevance and utility, providing the most current information on global educational trends. This update allows for thorough cross-national comparisons and assessments, enabling researchers and policymakers to identify patterns and correlations that impact student outcomes. By exploring the relationships between educational resources, teaching methodologies, and student performance, the learningtower package empowers users to draw informed conclusions and develop evidence-based strategies aimed at improving educational equity and effectiveness across diverse contexts.

Communication and Documentation Tools

Slack and Notion can be effectively utilized together to enhance team communication and documentation management. Slack serves as a real-time communication tool, allowing teams to quickly exchange information, discuss projects, and stay updated on tasks, making it ideal for team collaboration.

Notion, on the other hand, excels as a centralized workspace for recording and organizing important documents, such as meeting journals, project notes, and other key materials, ensuring that important information is organized and easily accessible.

By using Slack for dynamic conversations and Notion for structured documentation, teams can ensure seamless communication while maintaining an organized record of all important documents, meeting notes, and long-term planning.

3 Goals

The motivation for developing the learningtower package was sparked by the announcement of the PISA 2018 results, which caused a collective wringing of hands in the Australian press, with headlines such as "Vital Signs: Australia's slipping student scores will lead to greater income inequality" and "In China, Nicholas studied math 20 hours a week. In Australia, it's three". That's when several academics from Australia, New Zealand, and Indonesia decided to make things easier by providing easy access to PISA scores as part of the ROpenSci OzUnconf, which was held in Sydney from December 11 to 13, 2019.

Specific Goals related to the Learningtower package

1. Simplified Access to Complete PISA Data: Make a user-friendly R package available that makes it easier to access a well selected, reliable, and complete subset of PISA data from 2000 to the most recent year. By doing this, users will need to spend less time and technical effort downloading, cleaning, and standardising the data.
2. Improved Data for Comparative Analysis: Make it possible to conduct longitudinal and cross-sectional studies of educational performance across nations, giving researchers the ability to

monitor trends over time and evaluate how different socioeconomic factors affect student outcomes.

3. Emphasis on Educational Equity: Encourage the investigation of performance gaps, paying special attention to variables including gender, socioeconomic position, and school resources. This goal is to enable policymakers and educational academics to recognise and resolve disparities both within and across nations.

4. Promoting Policy-Relevant Insights: Make it possible for academics and policymakers to obtain practical insights that guide instructional techniques, particularly with regard to achievement gaps. The package aids in the development of policy interventions aimed at underperforming populations by examining the variables that affect student success.

5. Simple Usability for the R Community: Provide thorough documentation, effective data structures in R, and sample analytic code so that people with different levels of experience can interact with PISA data for educational research.

6. Continuous upgrades and Data Consistency: Make sure that learningtower stays pertinent for the demands of contemporary research by committing to frequent package upgrades that incorporate fresh PISA data as it becomes available (next in 2025). Furthermore, in order to accommodate modifications in OECD schedules, the program guarantees consistency of variables across several assessment years in order to handle post-COVID-19 education dynamics.

7. Encouraging Reproducibility and Transparency: Make the carefully selected PISA data and analytic techniques publicly accessible via GitHub to encourage transparency and allow other researchers to duplicate and expand on the results.

By achieving these objectives, the learningtower package hopes to become a vital tool for educational research, advancing evidence-based perspectives on global trends in education and aiding initiatives to promote fair educational opportunities across the globe.

With a focus on PISA data from 2000 to 2022, the learningtower package is a strong and adaptable tool for evaluating educational data globally. Hence this report is aim to be an example of how to utilize to answer some research questions by applying various methodologies and statistical computations on the learningtower datasets.

We will mainly utilize the 2022 PISA data and scores for illustrative purposes throughout the analysis section. We decided to answer a few intriguing questions on the PISA data and see if we could identify any interesting trends or insights utilizing this dataset. Some of these questions include if there is any significant gender difference between girls and boys and explore their performance in the areas of mathematics, reading, and science. Furthermore, we will inspect the various socioeconomic characteristics reflected in the student data and investigate if they have any substantial impact on the scores of these 15-year-olds. Furthermore We will delve into few highlight countries' score history and study the pandemic effects on students' academic performance to uncover some noteworthy trends, additionally, we will revisit the gender disparities across the years to see if the gap has narrowed over time.

4 Methodology

The learningtower R program was developed through a series of methodical procedures, including data collection, processing, variable consistency checks, and analysis, for the study of PISA data from 2000 to nowadays. Each phase was meant to ensure that the data remains robust, consistent, and available for educational research and comparative studies.

1. Data Acquisition and Import

   A. Data Download: The most recent PISA datasets, which included student and school data from several nations, were downloaded in SAS or SPSS formats from the OECD website

   B. Data Loading in R: Following the download, the data was loaded into the R environment using scripts with the help of `haven` package(Wickham, Miller & Smith 2023) that made managing big SPSS/SAS files easier and guaranteed R compatibility.

2. Data Cleaning and Transformation

   A. Initial Cleaning: To eliminate discrepancies, including missing or incorrect entries, and to reformat categorical variables for standardisation, data wrangling programs were used. The data was prepared for additional processing thanks to this first cleaning.

   B. Variable Recategorisation: To ensure uniformity between PISA years, variables of interest were reclassified where needed.

   C. Taking care of Missing Variables: The 2022 dataset lacked some variables, including "possession of desk." These variables were either explicitly selected as character variables or, when appropriate, substituted with comparable indications in order to address this.

3. Ensuring Variable Consistency

   A. Cross-Year Alignment: Maintaining the consistency of important variables between PISA assessment years was a significant methodological difficulty. Some variables, such as the WEALTH index, were absent from newer datasets due to changes in questionnaire design.

To retain a measure of socioeconomic level in these situations, other variables such as ESCS (Economic, Social, and Cultural level) were employed.

B. Categorisation Adjustments: To guarantee consistency in analysis, the classification for parental education levels, household belongings, and technological access was standardised across datasets.

4. Data Transformation and Storage

A. Data Transformation: The processed data was transformed and saved as.rds files after being cleaned and having its consistency checked. The cleaned and categorised datasets are stored in these RDS files, which are small and easy to load quickly in R.

B. File Organisation by Year: To assist cross-sectional research within each year and to enable longitudinal analysis across years, each PISA dataset was saved independently. This method guarantees that the data by year may be readily accessed by researchers without the need for extra processing.

C. File Storage: The final RDS file for each PISA year were then thoroughly vetted and made available in a separate GitHub repository.

5. Validation and Quality Checks

Each dataset was examined for accuracy and completeness following processing. Particularly for new or altered variables, the integrity of socioeconomic indicators and the coherence of variable definitions were verified twice.

6. Data Analysis Techniques

Bootstrap sampling was employed to create robust confidence intervals for analyses on gender gaps, socioeconomic effects, and longitudinal trends, ensuring reliable estimates. The dataset supports both cross-sectional and longitudinal educational research, enabling in-depth exploration of trends in gender disparities, socioeconomic factors, and the impact of various variables over time.

5 Overview of the data

5.1 Student Dataset

The dataset offers student-level information from a number of nations and captures variables that affect academic performance. it contains the 23 variables, which could be categorized into groups:

Year: represents the year of data collection, which is manually constructed by the contributor.

Country: specifies the country from which the student data has been collected, using country codes.

School's inforamtion: represents the unique identifier of each student's school.

Student's inforamtion: This group provides some information about each student in the dataset.

1. **Parent's education**: record the parent's highest level of education based on the International Standard Classification of Education (ISCED) levels, ranging from "less than ISCED1" to "ISCED 3B, C".
2. **Gender**: categorizes the gender of each student as "male" or "female".
3. **Household possession**: record several variables related to students' household resources. Including whether the student has access to a computer and internet at home, both marked as "yes" or "no." Additional household resources are indicated by variables for a desk, separate room, dishwasher, television, and car. The number of computers and laptops is also available. Finally, the number of books in the student's home is categorized into ranges, such as "0-10" or "101-200.
4. **Math, Read, Science**: These columns provide the scores in mathematics, reading, and science subjects, respectively.
5. **Stu_Wgt**: Represents the student weight, used for calculating weighted averages in the analysis to ensure representative data.
6. **Wealth**: This column provides a measure of the student's economic wealth, where higher values indicate greater wealth. However this variable is not recorded in 2022 dataset.
7. **ESCS**: Represents the Economic, Social, and Cultural Status index, which is a composite measure of a student's socio-economic background.

5.2 School Dataset

The school dataset covers a variety of educational topics and offers data about schools across multiple nations.

year: Year represents the year during which the data was collected.

country: Country refers to the countries from which the data was collected.

School's information:

1. **school_id**: A unique identifier for each school, allowing for consistent tracking of school-related data across different records and years.

2. **public_private**: Designates the type of school administration, distinguishing between public (government-funded) and private (independently funded) institutions.

3. **stratio**: Represents the student-teacher ratio, indicating the average number of students per teacher in the school. Lower ratios typically suggest smaller class sizes and potentially more individualized attention.

4. **staff_shortage**: A measure indicating the level of staffing challenges faced by the school. Positive values may suggest severe shortages, while negative values or zeros may indicate minimal issues.

5. **school_size**: The total number of students enrolled, which can reflect the school's capacity and influence on the learning environment. Larger schools may offer more diverse programs, while smaller ones might provide a more personalized setting.

6. **fund_gov**: the percentage of funding that the government provides to the school. Understanding the resources available for staffing, programs, and infrastructure can be greatly aided by this.

7. **fund_fees**: The proportion of money that came from student fees demonstrates the school's reliance on fee-based revenue, which is more usual in private institutions.

8. **fund_donation**: represents the proportion of funds raised through donations, which could be a sign of extra support systems or community involvement.

9. **sch_wgt**: In order to guarantee that the sample appropriately reflects the school population, school weight is utilised in statistical analysis, especially in weighted averages or survey data.

5.3 Countrycode Dataset

This dataset includes a mapping of a country/region's ISO code to its full name. More information on the participating countries can be found here.

6 Analysis

In this section we will illustrate how the `Learningtower` package can be utilized to answer some research questions by applying various methodologies and statistical computations on the `Learningtower` datasets.

We will solely utilise the 2022 PISA data and scores for illustrative purposes throughout the analysis section. Some of these questions include if there is any significant gender difference between girls and boys and explore their performance in the areas of mathematics, reading, and science. Furthermore, we will inspect the various socioeconomic characteristics reflected in the student data and investigate if they have any substantial impact on the scores of these students.

6.1 Gender Gap

Gender gaps have always been a topic of interest among researchers, and when it comes to PISA data and scores of 15-year-old students around the world, uncovering patterns based on their gender would help gain meaningful insights in the field of education for various education policymakers around the world. Based on the 2022 PISA results, let us see if there is a major gender disparity between girls and boys throughout the world in mathematics, reading, and science. To begin, we will create a 'data.frame' that stores the weighted average math score for each nation as well as the various regions of the countries grouped by country and gender, in order to create this `data.frame` and represent data in the tidy format we use the `tidyverse` (Wickham et al. 2019) R package. Survey weights are critical and must be used in the analysis to guarantee that each sampled student accurately represents the total number of pupils in the PISA population. In addition, we compute the gender difference between the two averages. To demonstrate the variability in the mean estimate, we use bootstrap sampling with replacement using the `map_dfr` function on the data and compute the same mean difference estimate. For each country, the empirical 90 percent confidence intervals are presented. The same process is used for reading and science test scores.

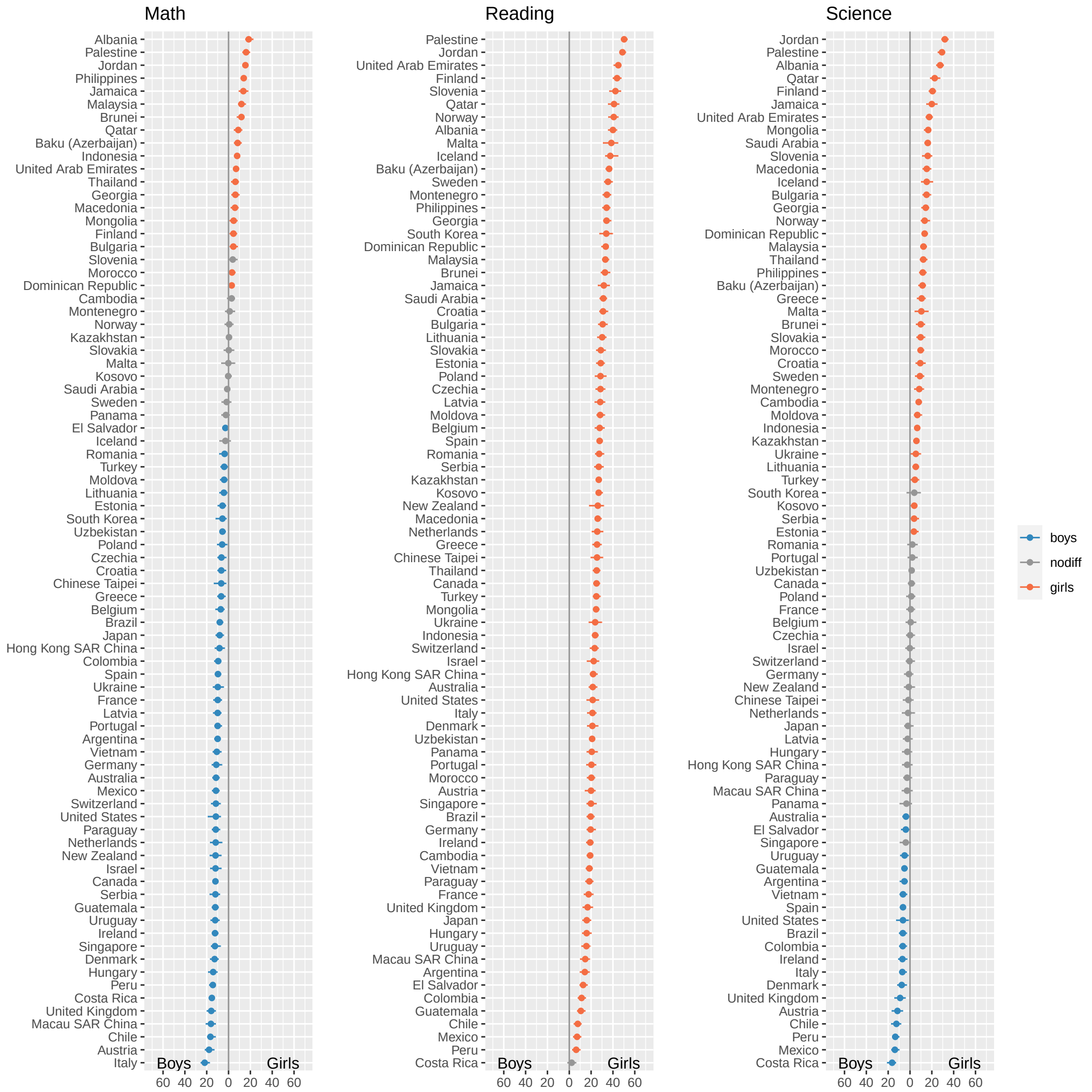


Figure 1: *The chart above depicts the gender gap difference in 15-year-olds' in math, reading, and science results in 2022. The scores to the right of the grey line represent the performances of the girls, while the scores to the left of the grey line represent the performances of the boys. One of the most intriguing conclusions we can get from this chart is that in the PISA experiment in 2022, girls from all countries outperformed boys in reading.The chart above depicts the gender gap difference in 15-year-olds' in math, reading, and science results in 2022. The scores to the right of the grey line represent the performances of the girls, while the scores to the left of the grey line represent the performances of the boys. One of the most intriguing conclusions we can get from this chart is that in the PISA experiment in 2022, girls from all countries outperformed boys in reading.*

Figure 1 illustrates the global disparities in mean math, reading, and science outcomes, before we get to the plot conclusion, let's have a look at the variables that have been plotted. The grey line here indicates a reference point, and all of the scores to the right of the grey line show the scores of girls in math, reading, and science. Similarly, the scores on the left side of this grey line indicate the scores of boys in the three disciplines. Based on Figure 1, because most math estimates and confidence intervals lie to the left of the grey line, we may conclude that most boys outperformed girls in math.

In nations such as Panama, Malta, Saudi Arabia, Sweden, Kazakhstan, Norway, Slovenia, Iceland, Kosovo, Cambodia, Montenegro and Slovakia, there is almost no gender difference in average math scores. When we look at the reading scores, we notice a remarkable trend in that all girls outpaced boys in reading in all countries in 2022. The highest reading scores were achieved by girls from Palestine, Jordan and United Arab Emirates. Looking further into the science plot, we see an unexpected pattern here where most countries have very little gender difference in science scores, implying that most boys and girls perform equally well in science. Boys from Costa Rica, Mexico and and Peru perform well in science and girls from Jordan, Palestine, and Albania are the top scores for science. Figure 1 helps us to depict the gender gap in math, reading, and science for all nations and regions that took part in the 2022 PISA experiment.

We gathered meaningful insights about the gender gap between girls and boys across the world from the above Figure 1 because this is a geographical research communication topic, the findings will help us better comprehend the score differences in the three educational disciplines using world maps. Let us continue to investigate and discover patterns and correlations using map visualization. To illustrate the gender gap difference between girls and boys throughout the world, we summarize regions on a country level and utilize the `map_data` function to get the latitude and longitude coordinates needed to construct a map for our data. We connect these latitude and longitude coordinates to our PISA data and render the world map using the `geom_polygon` function wrapped within `ggplot2` (Wickham 2016), the interactive features and placement of the plots are made using `plotly` (Sievert 2020) and `patchwork` (Pedersen 2020) packages in R.

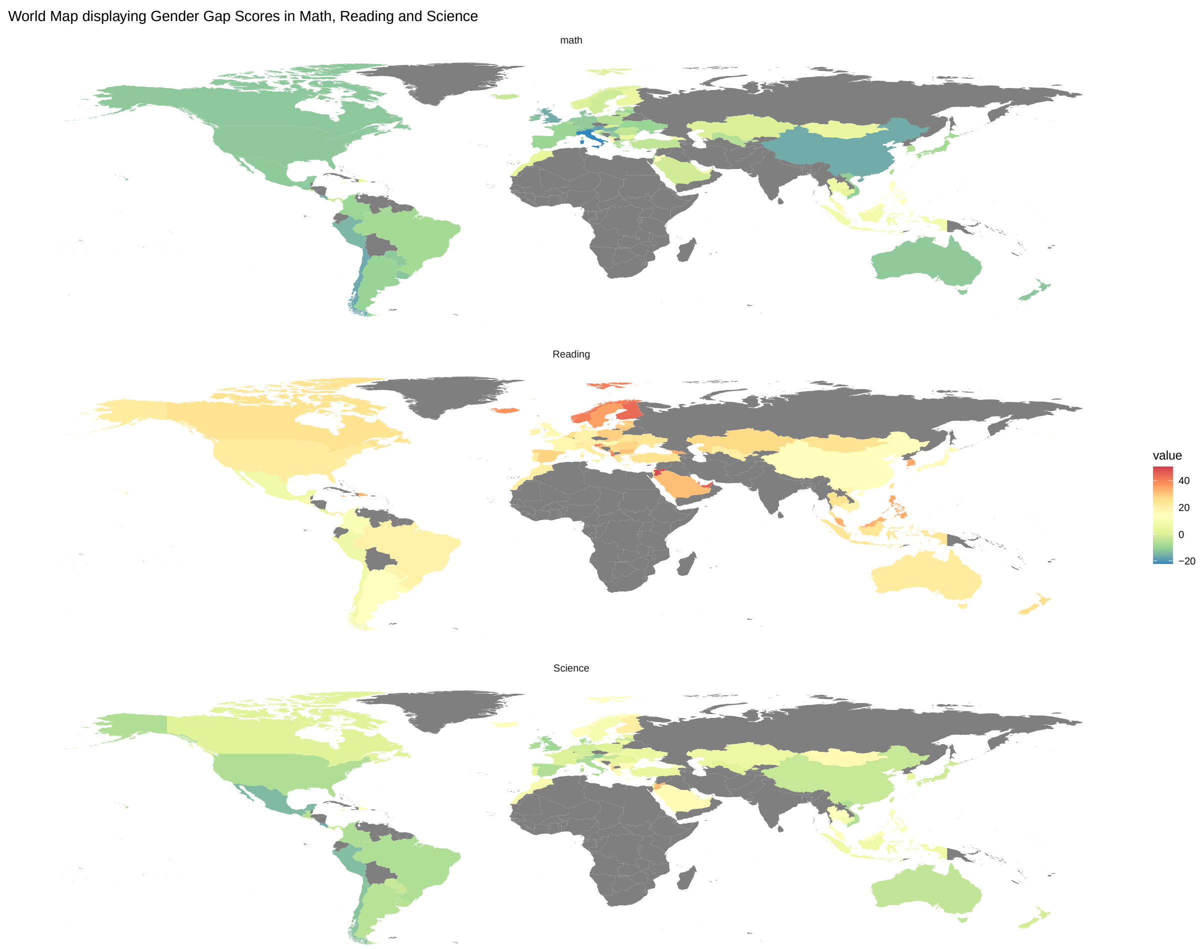


Figure 2: *Maps showing the gender gap in math, reading, and science results between girls and boys across the world. A positive score for a country indicates that girls outperformed boys in that country, whereas a negative score for a country difference indicates that boys outperformed girls in that country. The diverging colour scale makes it possible to interpret the range of scores and the also helps us intrepret the gender gap difference among these students across the globe.*

In the Figure 2, we have shown the gender gap difference between girls and boys in math, reading, and science in 2022. Map visualization aids in the comprehension of large volumes of data in a more efficient manner and increases the ability to compare outcomes across many geographical locations at a glance. In this figure, we see both positive and negative score difference scale ranges in all three maps. A positive country score indicates that girls outperformed boys in that country, whereas a negative country score shows that boys outscored girls in that country. The diverging spectral color scale and the legend of these maps makes it possible for us to deduce and identify regions across the globe showing large gender discrepancy between girls and boys. The grey colour for different geographic locations across the maps in Figure 2 indicates that these regions were not a part of the PISA experiment in year 2022.

Even though the map visualization embeds the same scores as Figure 2, one of the most striking thing on this map is the lack of data for the Africa continent. We see that there is less of a gender disparity seen in the science scores compared to maths and reading. In addition, the color scale for scores of each subject aids in identifying the countries that took part in the PISA experiment. As a result, in this section, we have seen the gender gap scores and striking trends between 15-year-old girls and boys in math, reading, and science. Our main conclusion from this gender study is the performance of girls in reading. The fewer gender disparity is evident in the science scores, and the majority of boys perform better than girls in mathematics.

7 Socioeconomic factors

Socioeconomic status is an economic and sociological complete measure of a person's work experience, economic access to resources, and social standing in relation to others. Do these socioeconomic factors influence students' academic performance? In this section, we will investigate if different socioeconomic factors owned by a family have a significant impact on a student's academic performance. The student dataset in the `learningtower` package contains scores of 15-year-olds from triennial testing across the world. This dataset also includes information about their parents' education, family wealth, gender, and ownership of computers, internet, cars, books, rooms, desks, and dishwashers. Next, we will mainly explore some fascinating aspects of the influence of a few socioeconomic factors on student performance in math, reading, and science. Let us further explore the impact of a selection of socioeconomic factors on the students' score.

Parent's education

Parents qualification is a vital element of childhood development. As previously stated, the student dataset in the package includes information regarding the parents qualification. In this section, we will investigate if both the mother's and father's qualifications have a significant impact on their child's performance. The mother's education and father's education variables are originally recorded in the student dataset in the `learningtower` package at distinct International Standard Classification of Education (ISCED) levels which are less than ISCED1 equivalent to ISCED 0, ISCED 1, ISCED 2, ISCED 3A and ISCED 3B, C, where:

- level 0 indicates pre-primary education or no education at all
- level 1 indicates primary education or the first stage of basic education
- level 2 indicates lower secondary education or the second stage of basic education, and
- level 3 indicates upper secondary education. ISCED level 3 have been further classified into three distinct levels, with ideally very little difference in their classification. This may also be found in the publication OECD Handbook for Internationally Comparative Education Statistics

(Economic Cooperation & Development 1999) published by OECD.

To determine the impact of the parents' qualification we first create data frames that are categorized by the various countries and regions and grouped by the father's and mother's qualification. We next compute the weighted average of math scores while accounting for student survey weights. Furthermore, we re-factored the parents qualification variable based on the multiple levels of classification, dividing it into four unique levels of education, namely early childhood, primary, lower, and secondary education. Furthermore, we display the weighted math average versus qualification colored by the re factored qualifications levels for both the mother and father using the `geom_quasirandom` function wrapped within `ggplot2` (Wickham 2016), we further plot this with the help of `viridis` (Garnier et al. 2021) and `patchwork` (Pedersen 2020) packages in R.

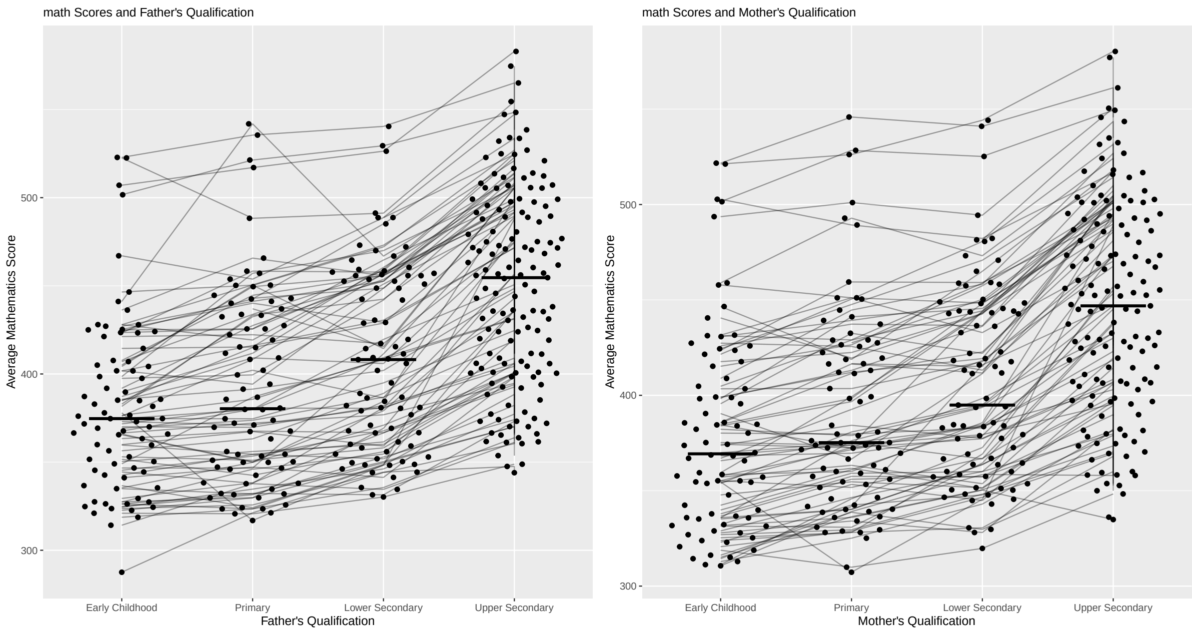


Figure 3: *The impact of parents' education on their children's academic progress is depicted in this graph. When the parents have greater levels of education, we see a considerable rise in scores and an increase in the median of scores for each category, as shown in the figure. In comparison to parents with lower levels of education qualifications. Parents who have tend to have upper secondary qualification or equivalent credentials their children are more likely to perform better in academics when compared with parent having lesser levels of qualifications.*

The Figure 3 depicts the impact of mothers' and fathers' qualifications on students academic performance. The Figure 3 allows us to deduce a very important and remarkable insight in which we see a constant increase in the students' academic performance when both mother and father qualifications shift towards higher levels of education. The bold horizontal black lines that we see in each category for mother's and father's qualification here represent median score for that qualification category across countries. As the parent attains higher qualifications, we notice an increasing trend in these medians for each category. Taking a closer look at the Figure 3, we can see that there is a considerable boost in scores when both the mother and father have upper secondary education. Furthermore, the `geom_quasirandom()` function in the `ggbeeswarm` (Clarke & Sherrill-Mix 2017) package makes this plot more accessible and understandable by providing a way to offset points inside categories to prevent overplotting. Thus, we can clearly see that both the mother's and father's qualifications has a significant influence on the student's academic performance, with the more educated the parent more likely to have their child academically performing better.

Technology Assisstance

Students are becoming more active and adept learners as technologies like computers and internet mature and becoming more commonplace over the past twenty years. We will investigate if having a computer with internet access at the age of 15 has a positive or negative impact on student academic achievement. We will plot the average math results of the several nations that participated in the PISA experiment in 2022 to determine the effect of owning a computer and having access to the internet. We first create `data.frame` that is grouped by the nations and the frequency of whether the student possesses a computer or not, as well as a students' access to the internet or not. We will plot this result against the weighted average mathematical score to determine the influence of various of television and internet on the student academic performance using the several functions available in the `ggplot2`(Wickham 2016) package and `patchwork` (Pedersen 2020) packages in R.

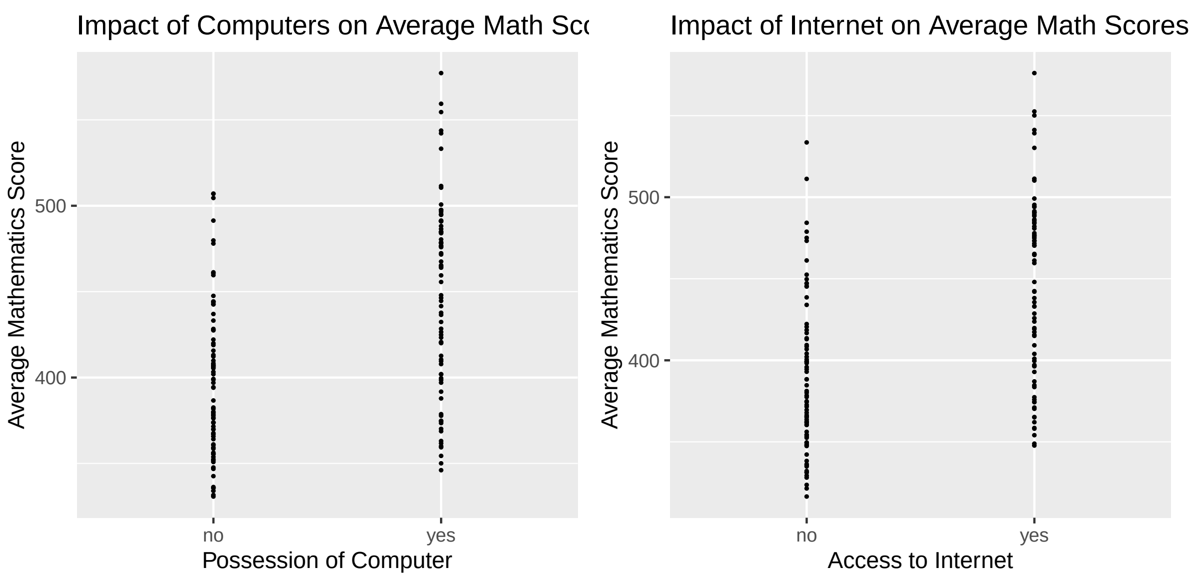


Figure 4: *Computers and the Internet are two of the most important inventions in the history of technology. In this figure, we observe the impact of owning a computer and having access to the internet on 15-year-old students all over the world. A remarkable finding from the plot is that all nations have higher scores in student performance when they own a computer and have access to the internet.*

In the Figure 4, we see that students who own a computer and have access to the internet consistently outperform students who do not own a computer or have access to the internet at all. No country has exempted from this finding. Thus, on average, a 15-year-old student's access to a computer and the internet is unquestionably has significant positive influence on their academic performance. While the increase in academic performance is expected, but the magnitude of this increase and the associated educational benefits may be used by policymakers to improve their own domestic access to these technologies.

Followed on previous discussion, computer has became an essential in learning experience. In this segment, we investigate the influence of number of computers by countries/regions, as well as whether this technology has a significant impact on students' academic performance. The computer variables that are recorded in the student dataset is a factor variable that records whether or not the students participating in this study have a computer and, if they do, the quantity of computers per family is recorded via the PISA survey. Especially, in 2022 dataset, the survey also included the laptop variable. The computer and laptop variables are initially recorded has four levels: "No computer/laptop", "1 computer/laptop", "2 computers/laptops", or "3+ computer/laptops", respectively. Because we are interested in researching the impact of these computers and laptops on the students' scores, we visualized the confidence intervals for each of these levels in order to determine the uncertainty of the results at each level. We begin with initially creating a `data.frame` that is grouped by country and the number of computers and laptops per household for each country. Next we fit a linear model between the math average with computer and laptops in the 2022 PISA data and finally plot the impact for all countries sorted as per the slope with the help of the functions available in the `ggplot2` (Wickham 2016) package and `patchwork` (Pedersen 2020) packages in R.

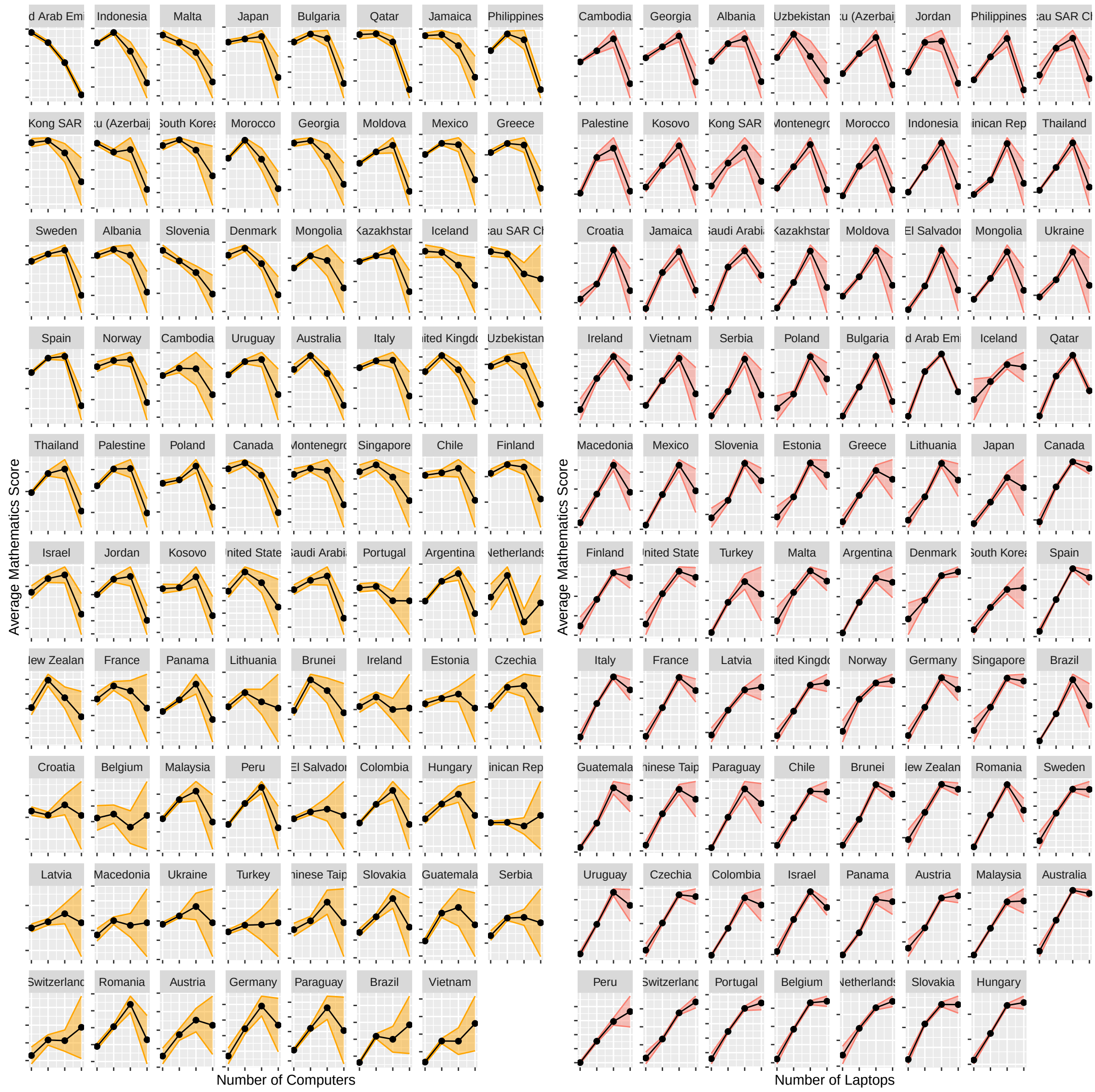


Figure 5: *Relationship between number of computers and laptops in a household and average math scores across countries. Number of computers/laptops ranges from 0 to 3 or more. The orange bands indicate 95 percent standard confidence intervals. The impact of computer/laptop on student performance is a contentious issue. It is interesting that the effect of computers and laptops are different across countries*

In the Figure 5, we can see highly striking patterns as well as a significant influence of computer/laptop on students' academic performance. We have arranged the nations in the Figure 5 according to the slope of math average scores fitted against the different levels of computer/laptop described previously. United Arab Emirates and Indonesia have a lower influence of computer on student performance, whereas Brazil and Vietnam have a rising tendency and therefore a larger impact of computer on students' performance. Furthermore, the confidence interval plotted in the figure Figure 5 show that there is a lot of uncertainty in the level of scores when a household have more computers in the majority of the countries. On the other hand, Cambodia and Georgia have a lower influence of laptop on student performance, whereas Slovakia and Hungary have a rising tendency and therefore a larger impact of laptops on students' performance. Taking a closer look we observe that when the slope of laptop increases in countries, compared to the slope of computer, the confidence interval of such countries becomes narrower. Hence laptop could have more potential educational benefit compared to computer. It's quite interesting because the similar nature of computer and laptop, we would assume the effect of these two assets should be similar, yet the Figure 5 has not only shown a different result. Nevertheless, having multiple computers and laptops may turn out to be having negative influence on student's performance in most of the countries, excessive access could lead to distractions or excessive screen time, which can negatively impact performance.

7.1 Temporal Analysis

The 2022 PISA results offer a unique opportunity to analyze the impact of the COVID-19 pandemic on student's academic performance. As countries faced prolonged school closures, remote learning challenges, and varying socio-economic pressures, concerns grew over potential learning losses and their effects on core academic skills. In this section, our temporal analysis will examine how student performance in each subject may have shifted compared to pre-pandemic data, providing insights into the pandemic's educational impact. Additionally, the study will revisit the gender gap, a persistent trend in PISA assessments. By investigating whether this gap has narrowed or persisted in 2022, we can better understand how gender disparities in education might have evolved, offering valuable guidance for future efforts to support equity and learning recovery worldwide.

Pandemic effects

To better comprehend pandemic effect on student's academic performance, We illustrate the temporal trend of Australia in comparison to a few other nations. We evaluate these countries performance using a statistical procedure bootstrapping using the `map_dfr` function which re-samples a single dataset to generate a large number of simulated samples. We will compare the results of these bootstrap samples across all the years they participated in PISA.

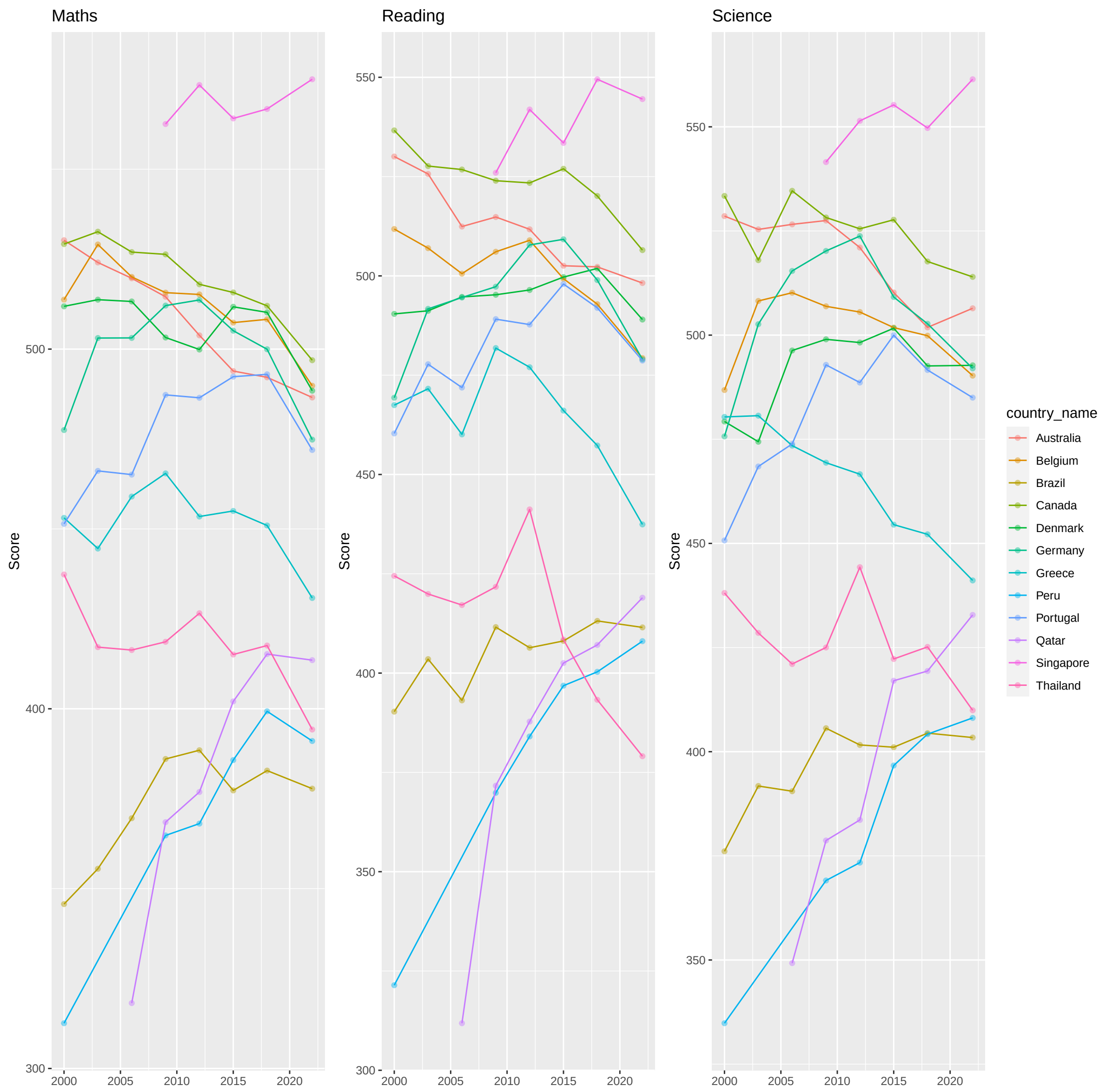
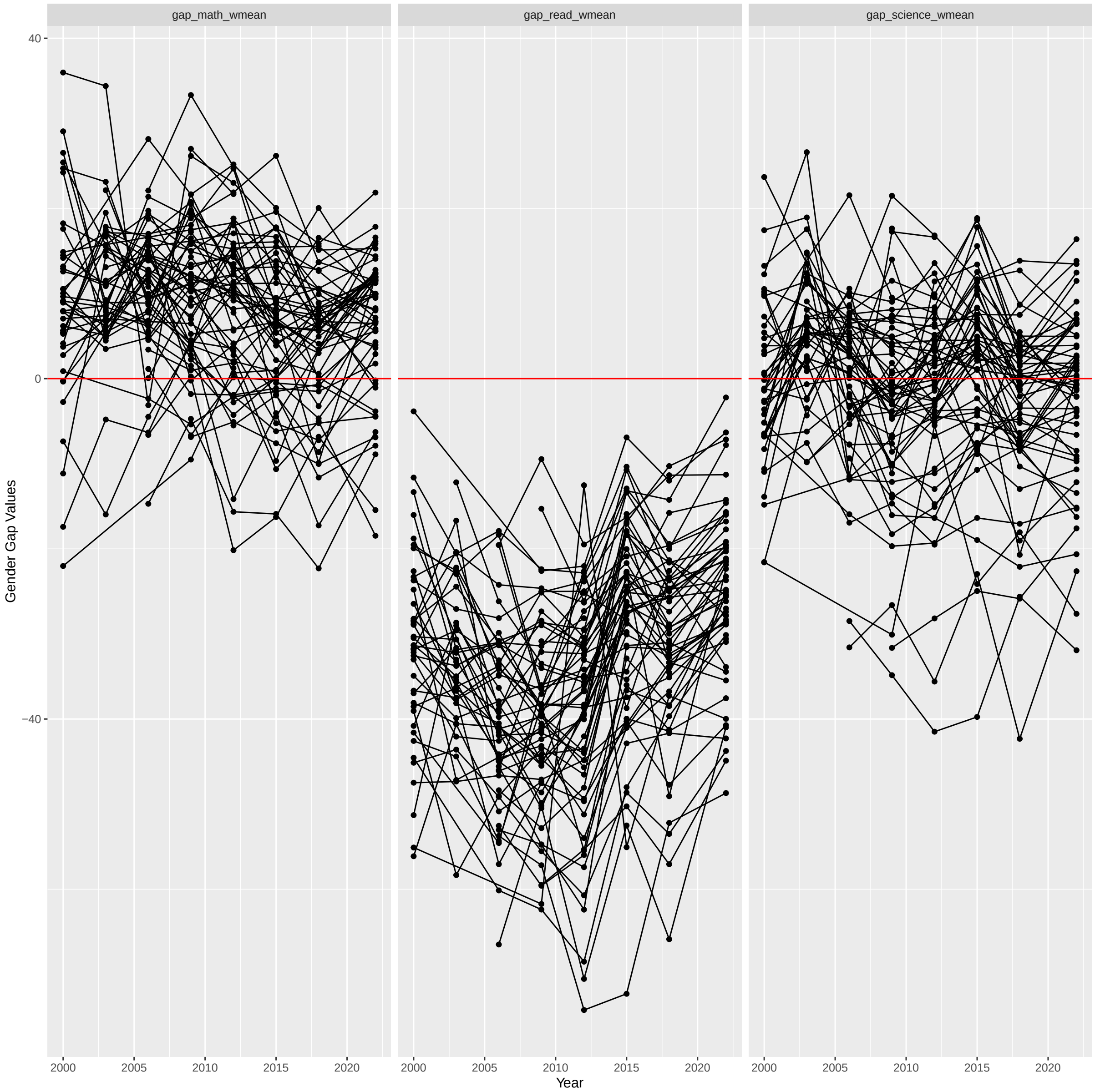


Figure 6: *Temporal patterns in math, reading, and science in a variety of countries. In this plot we could observe that there is a noticeable decline in scores in mathematics, with Singapore as an exception, showing improvement. Reading scores also decline in most countries, though Qatar and Peru exhibit an upward trend. For science, scores remain relatively stable, with no clear overall decline, as most countries maintain previous performance levels.*

Taking a deeper look at the Figure 6, we notice the changing scales of their scores in all three plots of math, reading, and science and we could observe that there's a obvious decline in mathematics score across countries, only Singapore still demonstrate increase in scores; same in reading most countries have decline, yet only Qatar and Peru have shown improvement. As for science, there's no clear drop in score, most countries have maintained in the same level as previous years. The extent of the academic losses in each country is varied depending on various factors. The consequence of the learning losses because of the Covid-19 school closures may extend beyond the academic realm. This loss of human capital will have enduring economic implications on not only the students themselves but also on their countries, constraining the country's productivity, economic output as well as the growth and development. As some educationist have raised their concern that a crisis in education is has arrived, and low-achieving students are being disproportionately affected, when these students enter the labor market, their earnings will be lower than would have been the case in the absence of the learning losses. Hence, the policymaker around the world have to make well designed strategies to mitigate the damage done by the pandemic so that our current and future generations would not suffer from this learning loss also prevent such rare black swan event from happening again if there's another pandemic hit the globe.

Gender Gaps Across Subjects and Years

In this section, We aim to examine the temporal trend in the gender gap across three core subjects. Our goal is to determine if the gap has narrowed over time, following up on previous analyses. We calculated the weighted means by gender for each subject, grouped by country and year, and filters for complete cases. We then compute gender gaps for each subject and visualize the trends over time, using `ggplot2`(Wickham 2016) and `brolgar`(Tierney, Cook & Prvan 2022) to display the shifts in these gaps across countries and years.

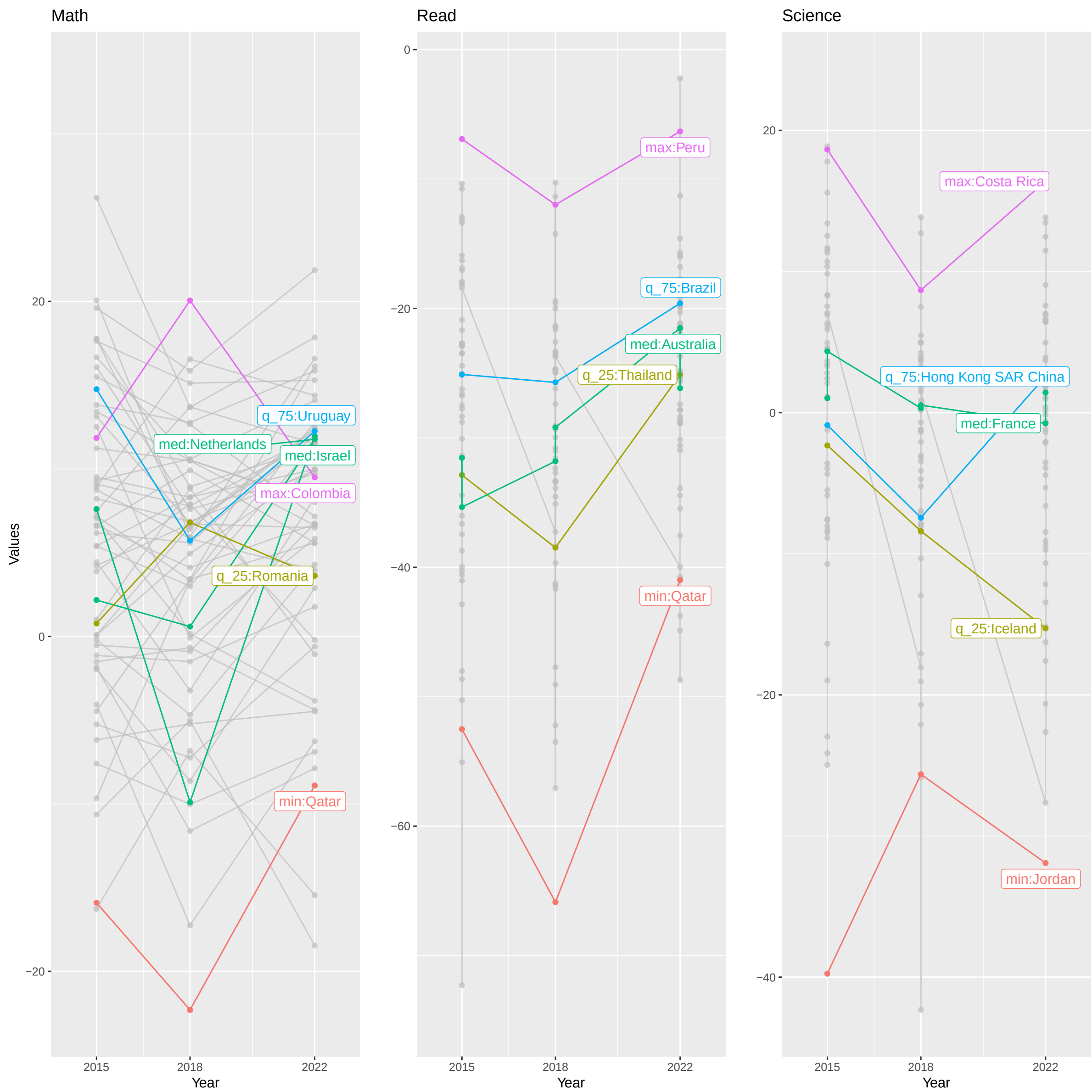


(a) *Gender Gap Values = average male score - average female score*

Figure 7: *The chart above depicts the average scores of gender gap difference in 15-year-olds' in math, reading, and science results. The gaps of math and science fluctuate around zero, indicating stability over time, the reading gap consistently favors females and remains relatively stable. This suggests that although the gender gap in math and science has not significantly changed, the persistent advantage in reading for females is evident across the years.*

From the Figure 7, we could observe that for math and science, the gender gaps appear relatively close to zero, with fluctuations over time but no consistent widening or narrowing trend across countries. In reading, however, a notable and consistent gap favors females, remaining relatively stable over time with some variation between countries. These results suggest that while the gender gap in math and science may not have significantly changed, the reading gap (female led) persists across years.

Because gender disparities is different in each country and the changing nature of countries' participation of the PISA, we want to investigate the changes within three assessments (2015, 2018 and 2022). By examining differences in focal subject's performance, we aim to identify whether gender disparities show consistent trends or fluctuate across years. Using data for each subject, we applied statistical functions to determine notable data points (such as the median and quartiles) and plotted these trends by country. With `ggplot2` (Wickham 2016) package, `gghighlight` (Yutani 2021), which used to highlight significant data points across countries, as well as `patchwork` (Pedersen 2020) to create the visuals for a comprehensive view of each subject's temporal patterns.



(a) *Gender Gap Values = average male score - average female score*

Figure 8: *Countries such as Colombia, Peru, and Costa Rica demonstrate the largest gender gaps in mathematics, reading, and science respectively, while Qatar consistently shows the least disparity. However, disparities in reading, where females often outperform males, remain significant in some regions. In traditionally male-dominated subjects like math and science, a gradual reduction in disparities indicates movement towards gender equality. However, in reading, where females typically outperform males, persistent gaps remain in certain regions.*

From the analysis depicted in Figure 8, it is evident that countries such as Colombia, Peru, and Costa Rica demonstrate the largest gender gaps in mathematics, reading, and science respectively, while Qatar consistently shows the least disparity. The trend in gender disparities is not uniform globally; some countries exhibit progress in narrowing gaps, particularly in traditionally male-dominated subjects like mathematics and science, indicating a movement towards gender equality. However, disparities in reading, where females often outperform males, remain significant in some regions.

In traditionally male-dominated subjects like math and science, a gradual reduction in disparities indicates movement towards gender equality. However, in reading, where females typically outperform males, persistent gaps remain in certain regions. These findings underscore that educational gender inequalities are not uniformly distributed globally, with their presence and magnitude influenced by various socio-cultural, economic, and policy-related factors unique to each country. Thus, addressing gender disparities in education requires a tailored approach that considers the specific context and challenges of each nation.

8 Discussion

8.1 Results

The learningtower package's study of PISA data reveals important educational trends that affect student performance globally, particularly in the areas of gender, socioeconomic status, and technology access. Girls typically outperform boys in reading across all countries, according to the gender-based data, with particularly large gaps observed in Jordan, Palestine, and the United Arab Emirates. This pattern implies that although reading is typically thought of as a subject in which girls do best, this disparity may potentially be exacerbated by cultural and educational variables. Though some nations, like Sweden and Kazakhstan, exhibit near parity, suggesting potential success in implementing gender-neutral or inclusive educational approaches in maths, boys still often perform better than girls in maths. In contrast, gender variations in science scores are negligible in many regions, indicating that science instruction may inherently support more balanced performance between boys and girls.

In every subject, socioeconomic considerations show up as important predictors of academic performance. Higher scores are typically attained by students with more educated parents and those from higher ESCS (Economic, Social, and Cultural Status) backgrounds. Learning is impacted by parental support, family wealth, and access to educational resources, as seen by the positive link found between socioeconomic resources and student performance. Additionally, having access to technology—essentials as home computers and internet connectivity—is substantially linked to better academic achievement; kids who have these resources often outperform those who do not. Performance differences are less in nations with higher levels of digital penetration, indicating that equal access to technology may be crucial in closing the achievement gap between kids from different socioeconomic backgrounds.

Student performance trends throughout time demonstrate the COVID-19 pandemic's effects, especially in mathematics, where 2022 scores fell in many nations. This pattern might be a reflection of the difficulties associated with distance learning and the scarcity of resources while schools are closed.

On the other hand, science and reading scores were comparatively stable, with several nations—like Peru and Qatar—even seeing improvements in their reading proficiency. This resiliency in science and reading might indicate that these courses were better served by online resources or that students were better able to adjust to distance learning for these skills. The significance of flexible teaching strategies and infrastructure is emphasised by the temporal analysis, which can protect educational systems from interruptions and support the maintenance of uniform learning outcomes across disciplines.

The learningtower package's mapping and visualisation capabilities offer a thorough understanding of these findings, facilitating more understandable cross-national comparisons and emphasising distinctive regional insights. The significance of investments in digital and educational resources is further supported by the fact that nations with strong digital infrastructure and fair socioeconomic conditions typically exhibit narrower achievement inequalities. Together, these results highlight the necessity of evidence-based approaches that tackle regional and national educational issues in addition to global trends. The learningtower package supports efforts to build more inclusive, equitable, and resilient educational systems around the world by educating educators and policymakers about these important discoveries.

8.2 Limitations

First, due to CRAN package size restrictions, incorporating the latest data may lead to excessive data sizes. Thus, a data curation strategy or compression technique should be explored to manage growing datasets efficiently. Second, inconsistencies arise because each survey may have unique questionnaire designs and variable coding systems, necessitating a thorough curation process each time to ensure variable consistency across different years. Third, missing or incomplete data in certain years and countries pose challenges, reducing the comparability of results across regions and time. Additionally, this analysis excludes recent assessments like Creative Thinking and Financial Literacy, which is optional for participant, as well as in student's questionnaire the expanded data on students' attitudes, well-being, and learning experiences. These exclusions would limit the ability to capture a more comprehensive view of student performance across broader dimensions, which may be significant for future analyses.

9 Conclusion

The learningtower package has been improved with the addition of the 2022 PISA data, providing researchers, educators, and policymakers with a useful tool for examining and comprehending student performance and school characteristics worldwide. This most recent version guarantees a consistent and thorough dataset covering the years 2000–2022, in addition to providing up-to-date insights concerning educational outcomes. The software enables precise cross-country comparisons and thorough longitudinal studies by preserving consistency in variables and data structures, both of which are essential for spotting and solving educational trends.

The learningtower package offers a strong framework for investigating important topics in education, including socioeconomic effects, gender disparities, and the effect of technology assistance in the classroom. Package users can explore the ways in which various factors, such as parental education levels and digital access, impact student accomplishment with this degree of exposure to comprehensive, curated data. This makes it possible for stakeholders to make data-driven choices that have a direct impact on educational policies and initiatives meant to raise educational quality and equity.

The learningtower package stresses the value of open, repeatable research in addition to its analytical capabilities. The package facilitates a collaborative environment where discoveries may be shared and validated across research groups by providing the data and tools in an easily accessible format. This openness promotes future developments in the discipline when new PISA data becomes available and enhances the validity of educational analyses.

In the future, the learningtower package will continue to be updated with new PISA cycles, maintaining its usefulness and relevance as a vital resource for researching worldwide trends in education. The package's capacity to include new data will guarantee that it continues to be an essential tool for comprehending and resolving educational inequities as the educational landscape changes, especially in reaction to crises like the COVID-19 pandemic. Learningtower will promote evidence-based educational advancements with continued contributions and enhancements, eventually leading to a more effective and equitable global education system.

10 Acknowledgement

We acknowledge the use of ChatGPT to refine the academic language and accuracy of my own work, including grammatical structures, punctuation and vocabulary. The output was then modified further to better represent our team's own tone and style of writing.

In addition, We would like to express our sincere gratitude to the developers of the learningtower package, it is through their previous cumulative efforts that we are able to compose and finish this report.

11 Git respository of the project

- Presentation and Report: https://github.com/Shabarish161/Learningtower_Rpackage

- Official package respository: https://github.com/kevinwang09/learningtower/?tab=readme-ov-file
- Masonry respository: https://github.com/kevinwang09/learningtower_masonry/tree/master

References

Clarke, E & S Sherrill-Mix (2017). *ggbeeswarm: Categorical Scatter (Violin Point) Plots*. R package version 0.6.0. https://CRAN.R-project.org/package=ggbeeswarm.

Economic Cooperation, O for & Development (1999). *ISCED-97 Implementation in OECD Countries*. Accessed: 2021-11-03. https://www.oecd.org/education/1841854.pdf.

Garnier, Simon, Ross, Noam, Rudis, Robert, Camargo, A Pedro, Sciaini, Marco, Scherer & Cédric (2021). *viridis - Colorblind-Friendly Color Maps for R*. R package version 0.6.2. https://sjmgarnier.github.io/viridis/.

Organization for Economic Cooperation and Development (2021a). *About OECD*. Accessed: 2021-11-03. https://www.oecd.org/about/.

Organization for Economic Cooperation and Development (2021b). *About PISA*. Accessed: 2021-11-03. https://www.oecd.org/pisa/.

Pedersen, TL (2020). *patchwork: The Composer of Plots*. R package version 1.1.1. https://CRAN.R-project.org/package=patchwork.

Sievert, C (2020). *Interactive Web-Based Data Visualization with R, plotly, and shiny*. Chapman and Hall/CRC. https://plotly-r.com.

Tierney, N, D Cook & T Prvan (2022). The R Journal: brolgar: An R package to BRowse Over Longitudinal Data Graphically and Analytically in R. *The R Journal* **14** (2). https://doi.org/10.32614/RJ-2022-023, 6–25.

Wang, K, P Yacobellis, E Siregar, S Romanes, K Fitter, G Valentino Dalla Riva, D Cook, N Tierney & P Dingorkar (2021). *learningtower: OECD PISA datasets from 2000-2018 in an easy-to-use format*. https://kevinwang09.github.io/learningtower/, https://github.com/kevinwang09/learningtower.

Wickham, H (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. https://ggplot2.tidyverse.org.

Wickham, H, M Averick, J Bryan, W Chang, LD McGowan, R François, G Grolemund, A Hayes, L Henry, J Hester, M Kuhn, TL Pedersen, E Miller, SM Bache, K Müller, J Ooms, D Robinson, DP Seidel, V Spinu, K Takahashi, D Vaughan, C Wilke, K Woo & H Yutani (2019). Welcome to the tidyverse. *Journal of Open Source Software* **4**(43), 1686.

Wickham, H, E Miller & D Smith (2023). *haven: Import and Export 'SPSS', 'Stata' and 'SAS' Files*. R package version 2.5.4, https://github.com/tidyverse/haven, https://github.com/WizardMac/ReadStat. https://haven.tidyverse.org.

Yutani, H (2021). *gghighlight: Highlight Lines and Points in 'ggplot2'*. R package version 0.3.2. https://CRAN.R-project.org/package=gghighlight.