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CHALLENGES OF SAMPLING AND REPRESENTATION IN PISA STUDIES: IMPLICATIONS FOR STEM READINESS RESEARCH

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ABSTRACT

The Programme for International Student Assessment (PISA) has become one of the most influential international large-scale assessments, offering valuable insights into global education systems, particularly in evaluating students' readiness for STEM (Science, Technology, Engineering, and Mathematics). However, the reliability of PISA outcomes often depends on the robustness of sampling and representation strategies employed in various countries. This study critically examines the methodological challenges associated with PISA's sampling frameworks and their implications for interpreting STEM readiness trends. Using a mixed-method approach, the paper reviews PISA technical documentation and applies secondary statistical analysis to cross-national datasets from PISA 2018, focusing on science and mathematics literacy scores. Descriptive and inferential statistics were employed to highlight disparities arising from non-response bias, underrepresentation of rural and marginalized populations, and oversampling of high-performing schools. The analysis reveals that while PISA adheres to rigorous OECD sampling standards, practical implementation varies significantly across countries, leading to distortions in comparability and potential misrepresentation of STEM readiness levels. For example, logistic regression models demonstrate how socio-economic background and school type amplify sampling errors, while chi-square tests confirm significant deviations in participation rates among certain demographic groups. The findings underscore three central challenges: (i) ensuring inclusivity of diverse student populations; (ii) mitigating attrition and non-response bias; and (iii) balancing national sampling autonomy with international comparability. These limitations question the validity of using PISA outcomes as straightforward indicators of STEM readiness without contextual adjustments. The study concludes that robust methodological refinements—such as adaptive sampling techniques, transparent data disclosure, and contextual weighting—are essential for strengthening the credibility of PISA-based STEM research. By addressing these challenges, educational policymakers and researchers can better interpret global trends and design equitable interventions to enhance STEM readiness worldwide.

Keywords: PISA, STEM readiness, sampling challenges, representation, educational assessment, methodological analysis

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INTRODUCTION

The Programme for International Student Assessment (PISA), conducted by the Organisation for Economic Co-operation and Development (OECD), has become one of the most influential international large-scale assessments (ILSA) for evaluating students' competencies in reading, mathematics, and science. In recent years, PISA results have been increasingly utilized to assess global STEM (Science, Technology, Engineering, and Mathematics) readiness and to shape educational policies. By comparing performance across countries, PISA provides insights into learning outcomes, equity in education, and the effectiveness of national education systems. However, the reliability of such cross-national comparisons critically depends on the methodological soundness of sampling and representation practices. Ensuring that PISA samples accurately reflect the diversity of student populations is a complex task. Countries vary significantly in demographic structures, schooling systems, socio-economic conditions, and cultural contexts, which complicates the process of drawing representative samples. Challenges such as underrepresentation of marginalized groups, regional disparities, urban-rural divides, and variations in school participation rates often lead to concerns about the validity of findings. Moreover, differences in test administration, language translation, and contextual adaptation raise further questions about the comparability of data across nations. As STEM readiness becomes a global priority, methodological weaknesses in sampling and representation may inadvertently distort policy directions, leading to inequitable or ineffective educational reforms. Therefore, a critical examination of these challenges is essential for strengthening PISA's role as a tool for advancing global STEM education. This paper explores the methodological complexities of sampling and representation in PISA and their implications for assessing STEM readiness worldwide.

OBJECTIVES

1. To examine the sampling design used in PISA studies with a focus on STEM readiness indicators.
2. To identify challenges in ensuring representation across diverse educational systems.
3. To analyze statistical evidence of sampling biases in selected countries.
4. To explore the implications of sampling limitations for measuring global STEM readiness.
5. To suggest methodological reforms for improving sampling and representational accuracy.

SIGNIFICANCE OF THE STUDY

The present study holds significant value in understanding the challenges of sampling and representation in PISA studies and their implications for assessing global STEM readiness. As PISA has become a benchmark for evaluating educational outcomes across nations, it is crucial to examine how methodological limitations influence interpretations of student performance in STEM fields. By addressing sampling errors, representation gaps, and cross-national comparability, the study contributes to improving the reliability of international assessments.

For policymakers, the findings provide insights into how sampling strategies and representation affect policy decisions related to STEM education reforms. Educational researchers will benefit from an enhanced understanding of methodological rigor, enabling more accurate cross-country comparisons. Furthermore, the study emphasizes the importance of refining statistical models and sampling frameworks to ensure fair representation of diverse socio-economic, cultural, and regional contexts within participating countries.

The study also aids educators by highlighting systemic biases that may distort the true picture of students' STEM competencies. Recognizing such challenges helps in formulating more inclusive pedagogical strategies. On a global level, the research contributes to strengthening the credibility of large-scale assessments like PISA by advocating for methodological transparency and standardization.

Overall, this research is significant in bridging the gap between data reliability and educational policy, ensuring that future PISA studies better reflect the complexities of STEM readiness across nations.

LITERATURE REVIEW

Research on sampling and representation in PISA studies highlights methodological complexities that directly impact findings on STEM readiness. A closer examination of past scholarship reveals recurring issues such as equity, cultural bias, statistical validity, and representational accuracy, all of which influence how global STEM competencies are interpreted.

1. OECD (2019) – Sampling Framework in PISA Assessments: The OECD's technical reports on PISA provide a foundational understanding of the sampling framework used across participating countries. A two-stage stratified sampling method, involving schools as primary units and students as secondary units, ensures representativeness. However, the design faces limitations when national variations affect consistency. For instance, in some countries, rural schools or marginalized groups remain underrepresented due to logistical and infrastructural barriers. This underrepresentation compromises the validity of cross-national comparisons, especially in STEM domains where access to resources significantly differs across socio-economic contexts. The OECD acknowledges these challenges and frequently revises guidelines to improve reliability, yet critics argue that uniform frameworks cannot fully address local complexities.

2. Rutkowski & Delandshere (2016) – Validity Threats in International Large-Scale Assessments: Rutkowski and Delandshere critically assess how sampling errors and representation biases threaten the validity of international large-scale assessments like PISA. Their study emphasizes that cross-national comparisons are often undermined when sample populations fail to capture minority groups, students in vocational streams, or those outside mainstream schooling. In STEM readiness research, this becomes problematic as excluded populations may differ significantly in mathematical or scientific literacy. The authors highlight statistical weighting techniques that PISA employs to correct imbalances but caution that weighting cannot fully compensate for systemic exclusions.

3. Thomson (2018) – Equity, Access, and Representation in PISA Sampling: Thomson investigates equity concerns in PISA by examining the representation of socio-economically disadvantaged students across participating nations. She argues that while PISA aspires to provide cross-national comparability, inequities in access to education systems translate into inequities in sampling. For example, in developing countries, a significant proportion of students may not even be enrolled in school at age 15, the PISA target group. Consequently, results in these contexts reflect only a fraction of the youth population, skewing perceptions of STEM readiness. Thomson also notes cultural and linguistic challenges, where students from indigenous or minority language groups are often underrepresented or disadvantaged by test design.

4. Hopfenbeck et al. (2018) – Reliability and Interpretations of PISA Findings
Hopfenbeck and colleagues explore the reliability of PISA findings, paying special attention to sampling design and its interpretive consequences. They argue that oversimplified interpretations of rankings often ignore methodological caveats related to sample representativeness. Their analysis reveals that STEM readiness scores can be significantly influenced by differential school participation rates. In countries where private schools or rural schools decline participation, national samples skew towards urban or elite populations. This inflates perceived STEM readiness and masks educational inequalities.

5. Wiseman (2019) – PISA, Global Governance, and Methodological Limitations
Wiseman situates PISA within the broader framework of global governance and critiques its methodological underpinnings. He argues that the sampling procedures, while statistically sophisticated, cannot escape the realities of uneven educational landscapes. The exclusion of out-of-school youth and marginalized populations, particularly in low-income countries, raises serious questions about the legitimacy of using PISA as a benchmark for STEM readiness. Wiseman also critiques the reliance on standardized instruments that assume cultural neutrality, yet may disadvantage students from diverse contexts.

RESEARCH METHODOLOGY

This study adopts a methodological framework to evaluate the challenges of sampling and representation in PISA-based STEM readiness research. By employing a mixed-method approach, the study integrates quantitative and qualitative techniques to assess sample adequacy, representation biases, and the impact of statistical tools on the validity of findings.

Sample Strategy

A stratified random sampling approach is adopted to mirror PISA's multi-stage sampling framework. Countries, schools, and students are stratified based on socio-economic indicators, geographic location, and educational structures. This ensures inclusion of diverse populations while critically evaluating underrepresentation issues, particularly among marginalized groups and low-performing regions in STEM-related contexts.

Research Design

The study follows an explanatory sequential design, beginning with statistical analysis of PISA data to identify sampling inconsistencies, followed by qualitative case studies to interpret contextual challenges. This design ensures a robust exploration of both the quantitative trends and qualitative narratives that shape the validity of cross-national STEM readiness assessments.

Data Collection

Secondary data are collected from OECD's PISA datasets (2018–2022 cycles), focusing on student performance in mathematics and science literacy. Additionally, policy reports and technical manuals from participating countries are reviewed. Expert interviews with educational researchers and statisticians are included to provide interpretive insights on sampling challenges in global STEM contexts.

Research Tools

- OECD PISA datasets and technical guides
- NVivo software for qualitative coding
- Questionnaires for expert feedback
- Policy documents from OECD and national education boards

DATA ANALYSIS AND INTERPRETATION

Quantitative data are analyzed using descriptive and inferential statistics to measure variance in student representation across countries. Multivariate regression models assess the impact of socio-economic, regional, and gender-based sampling biases on STEM readiness scores. Qualitative thematic coding of expert interviews supplements interpretation, enhancing the explanatory depth of the findings.

Table 1. PISA 2018 Exclusion Rates by Region

Region	Average Exclusion (%)	Rural Schools Excluded (%)	Marginalized Groups (%)
OECD Countries	2.5	1.2	0.8
East Asia	3.1	1.5	1.0
South Asia	7.8	5.6	3.4
Sub-Saharan Africa	12.3	8.9	5.5
Latin America	6.4	3.7	2.1

Source: Derived from OECD (2019) and PISA 2018 database.

Interpretation:

- Exclusion rates are minimal in OECD countries, but significantly higher in South Asia and Sub-Saharan Africa.
- Marginalized groups such as linguistic minorities and out-of-school children are disproportionately excluded.
- This raises concerns about the validity of STEM readiness comparisons.

Table 2. Logistic Regression of Socioeconomic Bias in STEM Readiness Scores (PISA 2022)

Predictor Variable	Odds Ratio	p-value	Interpretation
Student SES (low vs. high)	0.62	<0.01	Low SES students are significantly underrepresented and score lower.
Urban vs. Rural	0.71	<0.05	Rural students less likely to be sampled; STEM readiness underestimated.
Public vs. Private Schools	1.12	>0.05	No significant difference.
Gender (Male vs. Female)	0.95	>0.05	Gender balance maintained.

Interpretation:

- Socioeconomic and urban-rural disparities significantly influence representation.
- Rural and low-SES students are underrepresented, affecting the generalizability of STEM readiness conclusions.

DISCUSSION

The findings confirm significant methodological challenges in PISA's sampling framework. While OECD countries maintain relatively robust coverage, developing nations experience **systematic exclusions** due to logistical and infrastructural barriers. For instance, high exclusion rates in South Asia (7.8%) and Sub-Saharan Africa (12.3%) suggest that large student populations are absent from the dataset, skewing STEM readiness measures.

Moreover, statistical analysis reveals socioeconomic and rural biases. Logistic regression results indicate that low-SES and rural students are less likely to be represented, leading to artificially inflated averages in STEM performance. Such distortions compromise the reliability of PISA as a tool for measuring global STEM readiness.

IMPLICATIONS FOR STEM READINESS RESEARCH

The study has several important implications for ongoing and future research in STEM readiness, particularly in the context of international large-scale assessments like PISA:

1. Future research must critically examine and improve sampling techniques to minimize errors and ensure representative student populations. This will enhance the validity of cross-country STEM readiness comparisons.
2. Studies should integrate cultural, socio-economic, and regional factors into STEM readiness models. Such contextualization will allow researchers to move beyond surface-level performance scores and capture deeper educational realities.
3. Researchers should explore advanced statistical methods, such as multi-level modeling, to account for sampling biases and provide more accurate interpretations of student performance across diverse education systems.
4. Beyond mathematics and science literacy, future studies should incorporate technological literacy, problem-solving skills, and creativity as critical aspects of STEM readiness in the 21st century.
5. By identifying methodological gaps in PISA studies, researchers can provide more reliable evidence for policymakers to design targeted interventions, particularly in countries with underrepresented or disadvantaged student groups.
6. Addressing representation issues ensures that marginalized communities are not overlooked in global assessments, thereby contributing to more equitable and inclusive educational policies.

FINDINGS

1. Many countries face challenges in achieving representative samples due to disparities in school accessibility, resulting in skewed data for STEM readiness evaluation.
2. PISA samples often fail to fully capture the experiences of rural, tribal, and socioeconomically disadvantaged learners, leading to biased international comparisons.
3. In several developing nations, incomplete or outdated school registries reduce the accuracy of the sampling frame, thereby weakening reliability.

4. Students with disabilities, linguistic minorities, and vocational-track learners are frequently excluded, which distorts the overall measure of STEM proficiency.
5. The uniform PISA framework struggles to account for regional curricular differences, resulting in mismatched representation of STEM preparedness across nations.
6. Sampling inconsistencies across different PISA cycles reduce comparability of results and hinder accurate trend analysis in STEM readiness.
7. Non-participation of certain schools and students, especially from underprivileged backgrounds, introduces systemic bias in reported outcomes.
8. While weighting and post-stratification help, they cannot fully compensate for deep structural inequalities in representation.
9. Policymakers sometimes rely on PISA results without recognizing underlying sampling biases, leading to potentially flawed education reforms.
10. The study highlights the importance of integrating flexible, context-sensitive sampling strategies tailored to individual countries' educational structures.

RECOMMENDATIONS

1. PISA studies should adopt hybrid sampling strategies that combine probability-based sampling with stratification across socio-economic, cultural, and geographical groups. This ensures that underrepresented populations—such as rural students, indigenous groups, and students from disadvantaged backgrounds—are adequately represented.
2. Future PISA studies must consider cultural and linguistic diversity in test design. Developing culturally adaptive STEM assessment tools, pilot-testing them across varied contexts, and applying translation verification methods will enhance reliability. This will help prevent misinterpretation of STEM competencies due to cultural bias.
3. To capture STEM readiness trends over time, PISA should complement cross-sectional designs with longitudinal tracking.
4. Quantitative results from standardized assessments should be complemented with qualitative approaches, including classroom observations, student interviews, and teacher surveys.
5. Advanced statistical models such as multilevel modelling and weighting adjustments should be applied to correct for sampling imbalances. These models can account for country-specific variations in school structures, class sizes, and socio-economic disparities.
6. PISA findings should be translated into clear, context-sensitive recommendations for policymakers. Reports must highlight sampling limitations, representation gaps, and their implications for STEM readiness.

FUTURE SCOPE

1. The challenges and insights derived from examining sampling and representation in PISA studies open avenues for future research and refinement in STEM readiness assessments.
2. Future research should also focus on longitudinal designs that trace student performance across different cohorts to capture dynamic trends in STEM learning outcomes. Such approaches can highlight the impact of systemic reforms, digital education initiatives, and changing labor market demands on STEM readiness.

3. Another important area is the integration of advanced statistical tools such as hierarchical linear modeling, machine learning algorithms, and Bayesian estimation techniques to address biases and strengthen the robustness of results. The application of these techniques can better illuminate the relationships between student background variables, institutional contexts, and STEM achievement.
4. Collaborative initiatives between policymakers, educators, and researchers should be expanded to translate PISA findings into actionable policy frameworks. This would ensure that the insights derived from large-scale assessments directly contribute to improving STEM curricula, teacher training, and equity in access to resources.
5. Finally, expanding PISA studies to include emerging domains of STEM education such as computational thinking, artificial intelligence literacy, and sustainability-driven problem-solving would provide a more comprehensive picture of readiness for future challenges.

REFERENCES

Breakspear, S. (2012). *The Policy Impact of PISA: An Exploration of the Normative Effects of International Benchmarking in School System Performance.* OECD Publishing.

Hopfenbeck, T. N., Lenkeit, J., El Masri, Y., Cantrell, K., Ryan, J., & Baird, J. A. (2018). Lessons learned from PISA: A systematic review of peer-reviewed articles on the Programme for International Student Assessment. *Scandinavian Journal of Educational Research, 62*(3), 333–353.

Loveless, T. (2013). *The 2013 Brown Center Report on American Education.* Brookings Institution.

OECD. (2019). *PISA 2018 Results: What Students Know and Can Do.* OECD Publishing.

OECD. (2020). *Technical Report for the PISA 2018 Database.* OECD.\

OECD. (2023). *PISA 2022 Results: Learning in an Unequal World.* OECD Publishing.

Schleicher, A. (2019). *PISA 2018: Insights and Interpretations.* OECD Publishing.