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SIMULATING NATIONAL GAINS THROUGH EDUCATION: A DIAGNOSTIC FRAMEWORK ANCHORED IN SDG 4 AND THE PHYSICAL SCIENCES

[1]Emeka, Chinedu Emmanuel and Ejiofor, Virginia Ebere[2]
[1]Management & Security Systems (MSS) Ltd, Awka, Nigeria
Email: chineduemeka111@gmail.com
[2]Department of Computer Science, Nnamdi Azikiwe University, Awka, Nigeria
Email: ve.ejiofor@unizik.edu.ng
Running Title: Education Quality and National Gains[1]

Abstract
The physical sciences—comprising physics, chemistry, earth sciences, and astronomy—form the bedrock of scientific literacy. Quality education, as articulated in the United Nations Sustainable Development Goal 4 (SDG 4), extends beyond access to schooling to embrace inclusion, equity, and lifelong learning. Mastery of the physical sciences cultivates analytical reasoning, data interpretation, and evidence-based decision-making—competencies that are transferable across disciplines and indispensable for sustainable development. This paper presents a simulation-based diagnostic framework that quantifies the relationship between educational quality and national development. Using normalized data from 101 countries, the model constructs composite performance measures and explores their distribution through scenario-oriented analysis. Results demonstrate wide cross-national variation in education-driven national gains, with most countries clustered in a mid-range performance band. A comparative assessment highlights Nigeria's current position relative to peer and benchmark countries and illustrates the potential for upward mobility through targeted education reforms. The approach provides a practical, data-driven tool for policymakers seeking to align investment in science education with national development outcomes.
Keywords: *Education quality; Physical sciences; SDG 4; National development; Simulation model*

Introduction

Education is universally recognized as a catalyst for human and economic progress. Sustainable Development Goal 4 (SDG 4) calls for inclusive and equitable quality education that promotes lifelong learning and the acquisition of relevant skills. Recent analyses emphasize that achieving SDG 4 requires not only access but also targeted investment in STEM-related skills that underpin sustainable development (STEMROBO Technologies, 2024; The contribution of education to economic growth: A review of the evidence, 2018). Within this framework, the physical sciences occupy a strategic position: they develop critical thinking, quantitative reasoning, and technological literacy—the intellectual foundations for addressing climate change, energy transitions, health innovation, and industrial competitiveness.

Empirical evidence confirms that cognitive skills in physical sciences, measured via international assessments, powerfully predict economic growth, with one standard deviation improvement linked to ~2% higher annual GDP gains (Hanushek & Woessmann, 2021; Hanushek & Woessmann, 2007).

Despite widespread agreement on the importance of education, quantifying how improvements in education—particularly science education—translate into measurable national gains remains challenging. Conventional education indicators often operate in isolation, while development indicators capture aggregated outcomes without explicitly linking them to underlying educational inputs. This disconnect limits the ability of policymakers to evaluate the potential impact of targeted education reforms.

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[1] Corresponding author: Emeka, Chinedu Emmanuel.
Email: chineduemeka111@gmail.com

This study addresses that gap by introducing a diagnostic simulation framework that mathematically links education-related attributes to national development outcomes. By integrating normalized, cross-national data into a composite scoring model, the framework enables systematic comparison, ranking, and scenario-based exploration of education-driven national gains. While studies link skills to growth (e.g., physics education driving technological transformation and productivity in Nigeria), isolated indicators limit reform evaluation, necessitating integrated diagnostic models. Empirical studies on physics education in Nigeria and similar contexts reinforce this view by linking physics-driven competencies to economic growth, technological innovation, and progress toward the Sustainable Development Goals (Improvement of Physics Education as a Hallmark for Economic Growth and National Development, 2024; Physics Education as a Tool for Achieving Sustainable Development Goals in Nigeria, 2023).

Materials and Methods

The simulation framework computes normalized composite scores based on selected education and development attributes. Each attribute value is normalized to the range [0, 1] using:

$$N = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

Attributes for which lower values indicate better performance, such as student–teacher ratio, are inverted as $1 - N$.

For each country, a **Final Attribute Score** is computed as the mean of selected normalized attributes. To account for data completeness and recency, a **Data Availability Score** is applied as a multiplicative weight. The resulting **Adjusted Attribute Score** represents the final composite measure used for analysis.

A PHP-based engine was developed to parse the input dataset, normalize selected attributes, compute composite scores, and generate country-level outputs. Countries were subsequently grouped into 4-percentage-point score bands to examine distributional patterns across performance tiers. The input dataset was constructed from multiple international sources to ensure comparability and coverage across 101 countries. Education-related and development-related indicators were drawn from the World Bank, including GDP in current US dollars, access to electricity, and pupil–teacher ratios (World Bank, n.d.-a; World Bank, n.d.-b; World Bank, n.d.-c). Additional macro-level attributes such as GDP rankings and life expectancy were sourced from Worldometer (n.d.-a, n.d.-b), while education spending profiles were obtained from World Population Review (n.d.). Mean years of schooling were extracted from RankedEx (n.d.), and research intensity was proxied by the number of scientific and technical journal articles as reported in publicly available compilations (Wikipedia, n.d.). Demographic projections and population structure were incorporated using the United Nations World Population Prospects (United Nations, Department of Economic and Social Affairs, Population Division, n.d.).

Results

Overview of computed scores

Adjusted Attribute Scores were computed for **101 countries**. Observed scores range from **18.56%** to **93.00%**, indicating substantial variation in education-driven national gains across countries. The minimum score corresponds to Nicaragua (18.56%), while the maximum score corresponds to Costa Rica (93.00%). Most countries fall within a broad mid-range band, reflecting moderate alignment between education quality and national outcomes. Table 1 summarizes the Adjusted Attribute Scores for selected countries, highlighting the wide range of education-driven national gains observed across the sample.

Country-Level Performance

Table 2 presents a comparative summary of Adjusted Attribute Scores for Nigeria and selected benchmark countries. Comparative analysis highlights clear differences among countries:

- **Nigeria** recorded an Adjusted Attribute Score of **47.31%**, placing it within the global mid-range cluster.
- **Brazil** achieved **53.01%**, indicating stronger performance relative to Nigeria.
- Advanced economies such as **Finland (56.80%)**, **Australia (62.78%)**, and **Japan (81.00%)** exhibit higher levels of alignment between education quality and national gains.
- Top-performing countries include **Costa Rica (93.00%)**, **Gambia (92.00%)**, and **Azerbaijan (88.00%)**.

Distribution By Score Bands

Countries were grouped into 4-percentage-point score bands to examine structural patterns. The distribution shows that:

- Very low scores (below 20%) are rare.
- The majority of countries cluster between **36% and 63%**.
- High-performing bands above 72% contain relatively few countries, reflecting cumulative advantages from sustained education quality and supporting infrastructure.

Representative band membership includes Brazil and Norway in the 52–55% band, Nigeria in the 44–47% band, and Costa Rica and Gambia in the 92–95% band.

Policy Simulation Illustration (Nigeria Case Example)

Table 3 provides a baseline comparison of education quality, science output, and national gain indicators for Nigeria and Brazil. To illustrate the diagnostic and exploratory capability of the simulation framework, a focused policy simulation was conducted using Nigeria as a reference case and Brazil as a comparative benchmark. The baseline comparison highlights substantial disparities in education quality, science output, and national gain outcomes between the two countries. Figure 1 depicts the relationship between the Education Quality Index (EQI) and the National Gain Index (NGI) across countries. Scenario-based adjustments were then applied to selected education variables for Nigeria, including increased science research output and improvements in student–teacher ratio. Table 4 summarizes the results of the policy simulation scenarios, showing the projected effects of targeted education improvements on Nigeria's EQI and NGI. The simulations indicate that targeted enhancements in these variables are associated with appreciable upward shifts in both the Education Quality Index (EQI) and the National Gain Index (NGI). A combined scenario incorporating simultaneous improvements in science output, teacher availability, and education spending yields the largest relative gain, demonstrating the sensitivity of national outcomes to coordinated education-sector investment. While these results are illustrative rather than predictive, they underscore the practical utility of the framework for exploring "what-if" reform pathways and assessing the relative impact of different education policy levers.

Discussion

The results confirm a structured relationship between education-related attributes—particularly those rooted in the physical sciences—and national development outcomes. Countries with stronger education investment, higher research output, and supportive infrastructure consistently achieve higher composite scores.

Nigeria's position at 47.31% illustrates both existing capacity and significant room for improvement. Its proximity to higher-performing mid-range countries suggests that targeted reforms in science education, teacher quality, and research capacity could realistically shift national performance into a higher development tier.

Notably, the presence of non-OECD countries among high-performing bands demonstrates that strong national gains are not exclusive to high-income economies. Rather, they reflect coordinated investment in education quality and enabling systems. This underscores the diagnostic value of the simulation framework as a policy-relevant tool rather than a purely descriptive ranking exercise.

Conclusion

This study presents a simulation-based diagnostic framework that quantitatively links education quality—particularly in the physical sciences—to national development outcomes. By integrating normalized, cross-national data into a composite scoring system, the framework enables objective comparison and distributional analysis across countries. The results highlight substantial global disparities while revealing clear pathways for upward mobility through targeted education reforms. As a practical decision-support tool, the framework offers policymakers a means to align investment in science education with broader sustainable development objectives under SDG 4.

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TABLE 1: TOP 10 COUNTRIES BY EQI

Rank	Country	EQI
1	Switzerland	0.617
2	Finland	0.617
3	Sweden	0.616
4	Iceland	0.612
5	Australia	0.603
6	Denmark	0.590
7	Cyprus	0.558
8	Belgium	0.544
9	Norway	0.543
10	New Zealand	0.539

Table 2: Top 10 Countries by NGI

Rank	Country	NGI
1	Luxembourg	0.982
2	Switzerland	0.923
3	Ireland	0.922
4	Norway	0.890
5	Singapore	0.880
6	Iceland	0.868
7	Qatar	0.846
8	Australia	0.835
9	Denmark	0.820
10	United States	0.815

Table 3 — Baseline Comparison (Nigeria vs Brazil)

Country	EQI	NGI	GDP per Capita (USD)	Science Output per Capita	Student–Teacher Ratio
Nigeria	0.180	0.171	2,085	63	37
Brazil	0.514	0.729	10,295	416	19

Table 4 — Policy Simulation Scenarios

Scenario	EQI	NGI (Projected)	Change vs Baseline
+100% Science Output	0.256	0.232	+36%
Student–Teacher Ratio → 25:1	0.275	0.243	+42%
Combined Investment Scenario	0.392	0.366	+114%