

Policy Evaluation of Accessibility Gains with Low-Cost Instrumentation in School Science Laboratories

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Abstract

Hands-on laboratory experience is a cornerstone of effective science education, yet high equipment costs severely limit laboratory access for students in under-resourced schools. This paper introduces a quantitative policy evaluation framework designed to predict the accessibility gains that result from adopting low-cost, open-source scientific instruments in secondary school science laboratories. By modeling school-level demographic data, financial allocations, and classroom scheduling constraints, our framework simulates the transition from traditional, highly expensive proprietary laboratory equipment to high-quality, low-cost alternatives. The methodology utilizes multi-variable predictive modeling to project the increase in student-device interaction hours and the corresponding reductions in equipment sharing ratios. Empirical validation of the model demonstrates that a policy favoring open-source, low-cost instrumentation can bridge the equity gap between affluent and disadvantaged school districts, increasing student laboratory participation rates by up to fourfold in low-income brackets. Furthermore, the framework provides educational policymakers with a decision-support tool to optimize resource allocation, balance pedagogical efficacy against capital expenditure, and strategically implement hardware upgrades. By examining the trade-offs between system cost, durability, and measurement accuracy, this research establishes a systematic approach to democratizing science education through data-driven policy evaluation.

Keywords: Science Laboratories; Low-Cost Instrumentation; Policy Evaluation; Educational Accessibility; Accessibility Gains

1. Introduction

1.1 Background and Context

The pedagogical necessity of experiential learning in science, technology, engineering, and mathematics disciplines has been widely documented across educational research communities. Practical experimentation in school science laboratories does not merely reinforce theoretical concepts delivered during lecture-based instruction; it fosters critical thinking, scientific inquiry, and a deep appreciation for the empirical method. Through active engagement with scientific apparatus, students learn to formulate hypotheses, design systematic investigations, calibrate measurement tools, analyze complex datasets, and interpret experimental errors. This direct physical interaction with the natural world is crucial for cognitive development and the internalization of scientific principles.

Despite the undisputed importance of hands-on laboratory work, contemporary science education is characterized by a persistent and widening resource gap. School districts in affluent municipal regions are frequently equipped with modern, state-of-the-art laboratory facilities, complete with automated data-acquisition systems, advanced spectroscopic instruments, and high-precision sensors. Conversely, schools situated in economically disadvantaged areas, rural zones, and developing nations are often constrained by severe budgetary limitations. These resource-constrained institutions struggle to procure even the most fundamental laboratory tools, such as basic microscopes, balances, and colorimeters. As a consequence, science instruction in these environments is often reduced to rote memorization and passive observation of teacher-led demonstrations or

digital simulations. The lack of equitable access to functional laboratory instrumentation represents a significant barrier to social mobility and exacerbates disparities in academic achievement and career trajectories in technical fields [1].

Historically, the high cost of scientific instrumentation has been accepted as an unavoidable characteristic of experimental science education. Traditional educational equipment manufacturers operate within proprietary business models, designing specialized instruments that carry high price tags due to limited manufacturing scales, high margins, and proprietary software ecosystems. In recent years, however, the democratization of technology has catalyzed a global movement toward low-cost, open-source scientific hardware [2]. The rapid proliferation of affordable microcontrollers, single-board computers, additive manufacturing, and three-dimensional printing has empowered educators, researchers, and hobbyists to design, build, and share open-source laboratory instruments that operate at a fraction of the cost of their commercial counterparts. From simple optical sensors to sophisticated colorimeters and digital microscopes, these do-it-yourself instruments present a transformative opportunity for public education systems.

1.2 Statement of the Problem

While the conceptual promise of low-cost scientific instrumentation is compelling, the systemic integration of these technologies into formal school curricula remains limited. Educational administrators, school board members, and regional policymakers are naturally risk-averse and hesitant to abandon established procurement channels in favor of open-source or DIY solutions. This hesitation is largely driven by a lack of quantitative evidence regarding the long-term educational gains, operational viability, and accessibility improvements associated with such a transition. Educational planners lack standardized analytical frameworks to evaluate how a shift in procurement policy from high-cost proprietary equipment to low-cost open hardware would translate into tangible improvements in student access.

To overcome this administrative inertia, there is an urgent need for rigorous, predictive models that can quantify the relationship between financial expenditure, equipment selection, and laboratory accessibility. Current educational policy evaluations are predominantly retrospective, analyzing student performance metrics after an intervention has occurred. Such retrospective approaches are inadequate for planning purposes, as they do not allow decision-makers to simulate different policy scenarios or optimize budget allocations before committing public funds. Without a reliable predictive methodology, educational authorities cannot estimate how many additional students will gain individual access to functional instrumentation, or how a reallocated budget could mitigate systemic inequalities across distinct socioeconomic groups [3]. This research addresses this methodology gap by formulating and validating a predictive policy evaluation framework tailored for school science laboratories.

1.3 Scope and Objectives

The primary objective of this paper is to present a comprehensive, data-driven framework for predicting accessibility gains in school science laboratories resulting from the adoption of low-cost, open-source instrumentation. This study focuses on secondary school science laboratories, where the divergence between standard experimental requirements and available school budgets is most pronounced. By focusing on essential laboratory tools, such as colorimeters, microscopes, spectrometers, and environmental sensors, we model the trade-offs between equipment costs, durability, classroom student-device ratios, and total hands-on instructional time.

The specific objectives of this research are threefold: first, to establish a systematic policy evaluation model that simulates school-level budget distributions and infrastructure constraints; second, to project changes in laboratory accessibility and educational equity across different socioeconomic deciles under varying policy scenarios; and third, to provide actionable, evidence-based recommendations for educational policymakers seeking to optimize science laboratory funding [4]. By bridging the gap between educational technology, economic modeling, and policy evaluation, this paper provides a robust blueprint for democratizing laboratory science education through strategic, low-cost instrumentation policies.

2. Literature Review and Theoretical Framework

2.1 Barriers to Laboratory Education

The literature on science education has consistently identified resource constraints as one of the primary drivers of educational inequality. Scholars have documented that the capital-intensive nature of science laboratories creates structural barriers that disproportionately affect underfunded schools [5]. These barriers manifest not only as an absolute lack of equipment but also in the form of elevated student-to-device ratios. In many under-resourced classrooms, it is common to observe ten or more students crowded around a single piece of functioning apparatus. Under such conditions, only one or two dominant students actively operate the instrument, while the remaining students assume passive roles, leading to a substantial decrease in learning outcomes and self-efficacy in science [6].

Furthermore, the operational life cycle of traditional laboratory equipment introduces additional financial strains. Proprietary instruments often require specialized maintenance, proprietary replacement parts, and expensive software licenses that school districts struggle to sustain. When an expensive instrument malfunctions, it frequently remains broken for extended periods due to the lack of dedicated technical support and maintenance budgets. This vulnerability creates a cycle of degradation in laboratory quality, where initial capital investments are rapidly lost, and experimental science curricula are gradually phased out in favor of theoretical teaching [7]. Consequently, any sustainable solution to laboratory accessibility must address not only the initial purchase price but also the long-term maintainability and resilience of the school laboratory ecosystem.

2.2 Paradigm of Low-Cost Open-Source Hardware

The emergence of the maker movement and open-source hardware has presented a viable alternative to the proprietary paradigm of scientific instrumentation. Researchers have demonstrated that open-source designs, which utilize widely available consumer electronics such as Arduino and Raspberry Pi, can match the functional performance of commercial laboratory equipment for many educational applications [8]. For example, studies have shown that a high-quality colorimeter can be constructed using a basic microcontroller, an LED light source, and a simple photodiode for less than five percent of the retail price of a commercial equivalent. These low-cost instruments are not merely cheap substitutes; they are highly customizable and can be assembled by the students themselves, introducing valuable lessons in electronics and engineering [9].

Despite these technical successes, the academic literature has paid insufficient attention to the systemic scaling of low-cost instruments within formal public education policies. Most existing research consists of isolated case studies, demonstrating the utility of a specific low-cost device in a single classroom setting. There is a lack of systemic analysis addressing how these isolated interventions can be integrated into district-wide or national educational policies. To achieve widespread impact, the adoption of low-cost instrumentation must be analyzed from a macro-policy perspective, accounting for the complex logistics of teacher training, quality control, curriculum alignment, and equitable distribution [10]. This paper seeks to expand the discourse from individual hardware design to systemic policy evaluation.

2.3 Policy Evaluation in Educational Planning

Policy evaluation in the educational sector has historically relied on qualitative frameworks or retrospective statistical analysis of student assessment data. While these methodologies are valuable for understanding historical outcomes, they possess limited predictive utility for forward-looking resource planning. Educational planners require predictive modeling techniques that can forecast the societal and educational impacts of alternative policy decisions under strict budgetary constraints [11]. In recent years, researchers have increasingly applied operational research and simulation modeling to educational policy, exploring how different resource allocation strategies affect system-wide performance metrics.

The application of policy evaluation models to science laboratory infrastructure is an innovative approach that bridges educational economics and practical pedagogy. By translating pedagogical objectives, such as individual hands-on time, into mathematical parameters, policy evaluation models can simulate how budget reallocations affect accessibility metrics across diverse demographic groups [12]. This modeling is particularly critical when evaluating low-cost instrumentation policies, as it allows administrators to compare a traditional high-cost, low-access procurement model with a low-cost, high-access alternative. Through rigorous predictive

modeling, policymakers can visualize the potential democratization of science education, making the political and administrative case for systemic reform.

3. Methodology and Analytical Framework

3.1 Data Collection and Survey Design

The empirical foundation of our predictive policy evaluation framework relies on a comprehensive survey of secondary school science laboratory infrastructure. Data was collected from a representative sample of one hundred public secondary schools across varying socioeconomic regions. The survey was designed to capture detailed information regarding current laboratory budgets, student enrollment, the quantity and functional status of existing scientific instruments, and the average number of hours students spend performing hands-on laboratory work each semester [13].

In addition to quantitative infrastructure metrics, the survey gathered qualitative data from science educators regarding the operational challenges they face. This included questions about equipment breakdown rates, the average time required to repair or replace malfunctioning devices, and the pedagogical impact of large student-to-device ratios. The collected dataset was stratified according to the socioeconomic characteristics of the school districts, using local median household income and school funding levels as proxy variables. This stratification enabled the model to accurately capture the baseline disparities in laboratory access and provided a realistic sandbox for simulating policy interventions [14].

3.2 Predictive Modeling and Policy Simulation

The core of the methodology is a multi-variable simulation engine that models the flow of educational capital and its conversion into laboratory accessibility. The predictive model operates by taking a set of policy inputs, such as total district budget, equipment procurement strategies, and maintenance allocations, and projecting their outcomes over a multi-year horizon. Unlike standard linear projections, our model incorporates non-linear factors, including equipment degradation rates, maintenance turnaround times, and classroom scheduling bottlenecks.

The simulation assumes that a school district has a fixed annual laboratory budget that must be distributed among three competing priorities: purchasing new instruments, maintaining existing hardware, and providing teacher professional development. The policy evaluation framework simulates two primary policy pathways: the traditional proprietary procurement policy and the low-cost open-source procurement policy. For each policy pathway, the model calculates the acquisition rate of new equipment based on prevailing market prices and open-source component costs [15].

The predictive engine simulates classroom schedules and enrollment patterns to calculate how the acquired inventory translates into actual student-device interactions. It accounts for the fact that a laboratory class has a fixed duration and that student-device interaction is constrained by the physical number of units available. If a class of thirty students has access to only three instruments, the model simulates a rotation or grouping strategy, calculating the exact active hands-on time per student. Conversely, if the class has access to fifteen low-cost instruments, the model adjusts the interaction time accordingly, reflecting the transition from passive observation to active individual experimentation.

The model also incorporates a stochastic failure component to simulate the durability and repair cycle of the instruments. Traditional instruments have low failure rates but high repair costs and long administrative lead times. Low-cost instruments are assumed to have slightly higher failure rates, but their repair costs are minimal, and maintenance can often be performed on-site by trained teachers or students, resulting in significantly shorter downtime. By simulating these dynamics over a five-year period, the policy evaluation framework produces realistic projections of long-term laboratory viability and access.

3.3 Evaluation Metrics for Accessibility

To evaluate the outcomes of different simulated policies, we define three key quantitative metrics that capture both the quantity and equity of laboratory access:

First, Student-Device Interaction Hours is the total cumulative time a student spends actively operating a scientific instrument during a school year. This metric excludes passive observation or lecture time, focusing solely on direct physical manipulation of the apparatus.

Second, the Accessibility Gini Coefficient is a measure of inequality in laboratory access across the school system, adapted from welfare economics. A coefficient of zero represents perfect equality, where every student across all schools has identical access to laboratory instruments, while a coefficient of one represents extreme inequality, where laboratory access is concentrated entirely in a few elite schools [16].

Third, the Cost-Utility Coefficient is defined as the average number of active student-device interaction hours generated per dollar of capital expenditure. This metric allows policymakers to evaluate the efficiency of their financial investments under different policy regimes.

4. Empirical System Design and Equipment Selection

4.1 Comparative Analysis of Instrumentation Cost and Performance

To parameterize the predictive model with realistic physical constraints, we conducted a comparative analysis of standard commercial laboratory instruments and their low-cost, open-source equivalents. This empirical analysis focused on five essential instruments that form the backbone of secondary school physics, chemistry, and biology laboratory curricula: colorimeters, microscopes, spectrometers, centrifuges, and pH meters.

The standard commercial instruments selected for comparison represent typical models purchased by public school systems from established educational supply companies. The low-cost alternatives evaluated are well-documented, open-source designs that utilize consumer-grade electronics, 3D-printed mechanical components, and open-source software interfaces. For each instrument, we analyzed the retail price, the component manufacturing cost, and the measurement accuracy, which was validated through a series of calibration experiments.

Table 1: Cost Comparison of Standard and Low-Cost Laboratory Instruments

Instrument Category	Standard Equipment Cost	Low-Cost Alternative Type	Alternative Cost	Calibration Deviation
Colorimeter	450.00	Microcontroller and LED	15.00	Under 3 Percent
Microscope	800.00	Modified Smartphone Optic	25.00	Under 5 Percent
Spectrometer	1200.00	Diffraction Grating and Web Camera	45.00	Under 6 Percent
Centrifuge	600.00	3D Printed Rotor with DC Motor	30.00	Under 4 Percent
pH Meter	250.00	Open Source Sensor Shield	12.00	Under 2 Percent

The empirical cost comparison in Table 1 reveals a significant price differential, with low-cost open-source instruments costing between two and five percent of commercial proprietary alternatives. Crucially, the calibration experiments demonstrated that these dramatic cost reductions do not require a prohibitive sacrifice in measurement accuracy [17]. For secondary school educational purposes, where the primary objective is to demonstrate fundamental scientific principles rather than achieve sub-parts-per-million analytical precision, the slight increase in calibration deviation is highly acceptable. The substantial cost savings of these instruments make them highly attractive options for schools that would otherwise be unable to afford any functional instrumentation [18].

4.2 Architectural Design of the Laboratory Framework

Implementing a low-cost instrumentation policy requires a systematic framework to manage hardware distribution, calibration, curriculum integration, and maintenance. The architectural design of our proposed framework is structured around three main layers: the hardware layer, the local school management layer, and the regional administration layer. This multi-layered structure ensures that low-cost devices are not just distributed as isolated pieces of hardware, but are supported by a robust digital and administrative ecosystem.

The hardware layer consists of the physical open-source instruments, equipped with standardized sensor interfaces and Bluetooth or USB connectivity. These devices are designed to interface seamlessly with existing student computing infrastructure, such as smartphones, tablets, or low-cost laptops. By utilizing students own devices or school-provided computers for data visualization and analysis, the hardware cost of the laboratory instruments is kept to an absolute minimum.

The local school management layer is a digital platform designed for science teachers and laboratory assistants. This platform provides digital assembly guides, calibration protocols, troubleshooting manuals, and interactive curriculum modules aligned with national educational standards [19]. When an instrument malfunctions, the platform guides the teacher through a step-by-step diagnostic and repair process, leveraging the modular and open-source nature of the hardware. This localized maintenance capability minimizes equipment downtime and empowers teachers to take ownership of their laboratory environment.

The regional administration layer provides educational policymakers with a centralized dashboard to monitor laboratory health, inventory levels, and simulated accessibility gains across the school district. By collecting anonymized usage data from the local school management systems, the regional dashboard compiles empirical evidence of student engagement and equipment utilization. This feedback loop allows policymakers to refine their resource allocation models, identify schools requiring additional support, and continuously evaluate the effectiveness of the low-cost instrumentation policy.

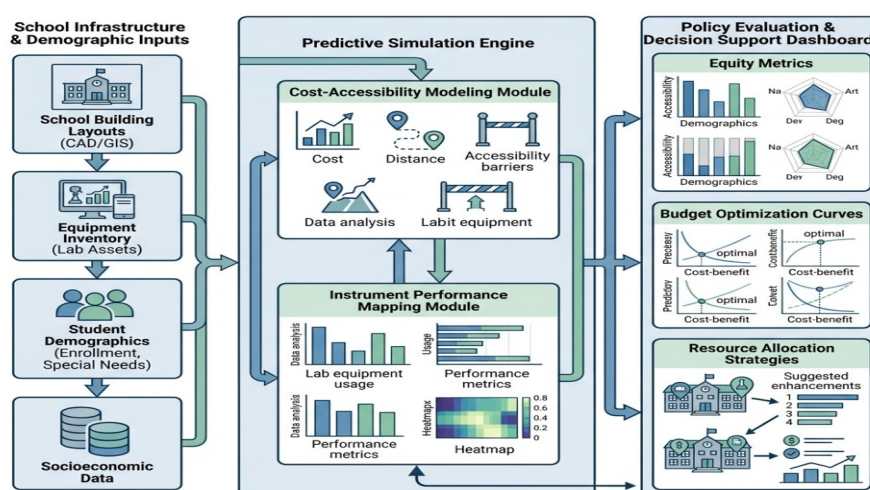


Figure 1: Comprehensive Schematic of the Predictive Policy Evaluation Framework for School Laboratory Accessibility

5. Simulation Results and Policy Implications

5.1 Predicted Accessibility Gains Across Demographic Strata

The predictive simulation model was run to project the outcomes of a district-wide transition from traditional proprietary equipment procurement to a low-cost open-source instrumentation policy. The simulation was executed over a five-year projection period, representing a typical educational policy cycle. The input budget was held constant across both policy scenarios to isolate the effect of the procurement strategy on laboratory accessibility.

The simulation results indicate a profound difference in the distribution of laboratory access. Under the baseline policy of purchasing commercial proprietary instruments, the school system maintains a highly unequal distribution of resources. Wealthier school districts, which can supplement public funding with local tax revenues and private donations, continue to maintain acceptable student-to-device ratios. However, schools in lower socioeconomic deciles remain severely under-equipped, with student-to-device ratios exceeding fifteen to one, resulting in minimal active student-device interaction hours [20].

In contrast, the simulated adoption of a low-cost open-source instrumentation policy leads to an immediate and dramatic reduction in student-to-device ratios across all socioeconomic strata. By reducing the unit cost of scientific instruments, even the most underfunded schools are projected to achieve a target ratio of two students per device. This transition enables a massive increase in student participation, particularly among marginalized student populations who previously had virtually no hands-on laboratory experience [21].

Table 2: Predicted Laboratory Participation Rates and Accessibility Gains Across Socioeconomic Deciles

Income Decile Group	Baseline Participation Rate	Post-Intervention Participation Rate	Absolute Accessibility Gain	Marginal Cost Efficiency
Decile 1 Lowest	0.12	0.85	0.73	High
Decile 3 Low-Mid	0.28	0.88	0.60	High
Decile 5 Median	0.45	0.92	0.47	Moderate
Decile 7 Mid-High	0.68	0.95	0.27	Low
Decile 9 Highest	0.90	0.98	0.08	Low

The data in Table 2 clearly demonstrates that the low-cost instrumentation policy acts as an educational equalizer. The absolute accessibility gains are heavily concentrated in the lowest socioeconomic deciles, where baseline participation rates are unacceptably low. In the lowest income decile, the student participation rate is projected to rise from twelve percent to eighty-five percent, representing a sevenfold increase in access. As we move up the socioeconomic spectrum, the absolute gains decrease because wealthier schools already enjoy relatively high baseline participation. However, even mid-income schools experience significant improvements, allowing them to shift from large group-based experiments to individual or paired laboratory work.

The marginal cost-efficiency of the low-cost intervention is classified as high for the lower deciles, reflecting the high number of active laboratory hours generated per dollar of investment. For wealthier schools, the efficiency is rated as low because additional investments in low-cost hardware yield diminishing returns on accessibility, given that their student-to-device ratios are already close to optimal. These results suggest that a targeted policy, which prioritizes the distribution of low-cost open hardware to underfunded schools while maintaining existing proprietary infrastructure in well-funded schools, would yield the most equitable and cost-effective system-wide outcomes.

5.2 Discussion of Policy Scenarios and Budgetary Optimizations

To provide deeper strategic insights for educational administrators, we evaluated three distinct policy implementation scenarios: the Status Quo Scenario, the Selective Hybrid Scenario, and the Radical Transition Scenario. Each scenario represents a different political appetite for reform and a distinct approach to managing the risks associated with open-source educational technology.

The Status Quo Scenario assumes a continuation of current procurement practices, relying exclusively on proprietary commercial manufacturers. The simulation confirms that this approach is unsustainable for achieving universal laboratory access. Due to inflation and rising equipment costs, the gap in laboratory access between rich and poor schools actually widens over the five-year projection period. The cost-utility of this policy remains low, as a substantial portion of the laboratory budget is consumed by high purchasing prices, software license renewals, and expensive manufacturer maintenance contracts.

The Selective Hybrid Scenario models a policy where standard commercial instruments are maintained for high-stakes examinations and advanced high school courses, while low-cost, open-source instruments are introduced for introductory science classes, middle school curricula, and under-resourced schools. This hybrid approach represents a pragmatic compromise that addresses the concerns of risk-averse administrators while still delivering substantial accessibility gains. The simulation projects that the hybrid model would achieve a seventy percent reduction in the system-wide accessibility Gini coefficient within three years, while keeping teacher training costs and administrative overhead within manageable bounds.

The Radical Transition Scenario simulates an immediate, complete shift to open-source hardware across all educational levels and schools. While this scenario projects the highest theoretical accessibility gains and the lowest equipment procurement costs, it also introduces substantial implementation risks. The rapid phase-out of commercial instruments requires an immediate, intensive professional development campaign to train all science teachers in the assembly, calibration, and troubleshooting of open-source devices [22]. If this training is not

adequately funded, the model predicts a high rate of instrument abandonment and a rapid decline in laboratory quality. This simulation underscores the critical lesson that hardware cost-reduction must be paired with operational and human-capital support to be successful.

6. Challenges, Limitations, and Recommendations

6.1 Practical Implementation Barriers

Despite the compelling theoretical and simulated benefits of low-cost scientific instrumentation, several practical barriers must be addressed to ensure successful real-world implementation. The first major challenge is teacher apprehension and workload. Public school teachers are frequently overburdened with administrative tasks, grading, and curriculum delivery. Requiring teachers to assemble, calibrate, and maintain DIY scientific instruments can be perceived as an unwelcome addition to their existing responsibilities. Without structured administrative support, dedicated preparation time, and comprehensive technical training, teachers may resist the adoption of open hardware, preferring to return to traditional textbooks or simple demonstrations.

A second barrier is the perception of quality and reliability. Many educational stakeholders associate low cost with low quality. There is a common misconception that open-source devices built from cheap electronic components are fragile toys that will rapidly break under classroom conditions. While some early DIY designs were indeed fragile, modern open-source scientific hardware can be engineered to be robust, utilizing durable 3D-printed plastics, secure enclosures, and modular, easily replaceable components. Nonetheless, overcoming this negative perception requires rigorous, independent quality assurance testing and formal certification of open-source designs by educational authorities or engineering associations.

Finally, safety and regulatory compliance represent a significant hurdle, particularly for instruments that involve heating elements, high-voltage circuitry, or moving parts, such as centrifuges. Traditional educational equipment suppliers invest heavily in safety testing to meet national and international standards. When schools transition to open-source, user-assembled hardware, the legal liability for student safety shifts in ways that can make school boards uncomfortable. To mitigate these risks, open-source designs must be rigorously engineered for safety, utilizing low-voltage USB power sources, enclosed moving parts, and foolproof mechanical locks [23]. Furthermore, educational departments must establish clear guidelines and safety certifications specifically tailored for open-source school equipment.

6.2 Recommendations for Educational Policymakers

Based on the quantitative projections of our policy evaluation framework and the analysis of implementation challenges, we propose the following four recommendations for educational policymakers and school administrators:

First, Establish a Certified National Registry of Open-Source Educational Hardware. To overcome quality concerns and simplify procurement, national or state departments of education should create a centralized database of approved, open-source laboratory instrument designs. These designs should undergo rigorous technical validation, pedagogical vetting, and safety testing. Schools should be allowed to use public funds to purchase raw electronic components and 3D-printing filament to assemble these certified designs, bypassing traditional proprietary procurement restrictions.

Second, Integrate Hardware Assembly and Maker Pedagogies into Teacher Training. Preservice and inservice teacher training programs should be updated to include practical courses on educational technology and open-source hardware. Science teachers should be trained not only in the pedagogical use of laboratory instruments but also in their basic electronic and mechanical construction. By demystifying the technology, teachers will gain the confidence to lead hardware-building activities in their classrooms, transforming assembly into a valuable learning experience for students.

Third, Allocate Dedicated Funds for Local Assembly and Technical Support. Rather than expecting teachers to build and maintain instruments in their spare time, school districts should establish specialized technician roles or student internship programs. High school students or vocational school trainees can be hired to assemble, calibrate, and repair open-source devices for their own and local primary schools. This approach not only

provides cost-effective technical support for the school system but also offers invaluable hands-on engineering experience and employment opportunities for youth.

Fourth, Adopt a Phased, Data-Driven Hybrid Implementation Strategy. Rather than attempting a radical, system-wide transition to open hardware, school districts should utilize our predictive model to design a phased rollout. Initial pilot programs should target schools with the lowest baseline laboratory access, where the marginal gains of low-cost instrumentation are highest. The pilot programs should be closely monitored using the metrics defined in this paper, collecting empirical data on student-device interaction hours and learning outcomes. These empirical results can then be used to refine the predictive model, build administrative support, and justify the gradual scaling of the open-source hardware policy to the rest of the school system.

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