

1. Implementing STEAM through Inquiry-Based Learning: A Case Study on Energy in Free Fall in Surinamese Secondary Education



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Abstract

This chapter examines a STEAM approach grounded in inquiry-based learning (IBL) to teach energy transformations during free fall in secondary physics, focusing specifically on students' understanding of the energy component in free fall. Conceptually, it addresses the challenge of engaging students in physics in ways that foster deep conceptual understanding, critical thinking, and hands-on problem-solving skills. The chapter situates this challenge within the Surinamese secondary education context, highlighting the potential of integrated STEAM approaches to bridge theoretical knowledge and practical application, while promoting equitable learning opportunities.

We conducted a quasi-experimental study with two first-year classes at Henry N. Hassankhan School (STEAM-IBL $n=15$; traditional $n=13$). The intervention consisted of two 45-minute STEAM-IBL lessons combining guided experiments, small-group problem-solving, and arts-

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integrated reflections, compared to lecture-based instruction in the control group. Learning outcomes were measured with a validated 25-item pre/post-test.

Results indicated that the STEAM-IBL group significantly outperformed the lecture-based group (+2.44 vs. +0.98 on a 0–10 scale), with a notable advantage in linking gravitational potential and kinetic energy to observable situations (paired t , $p < 0.001$; ANOVA $F(1,26)=20.84$, $p < 0.001$). These findings demonstrate that inquiry with low-cost experiments and multiple representations is both feasible and effective in multilingual, resource-constrained settings. Scaling such interventions, however, will require focused teacher professional development, access to simple simulations, and curricular alignment.

Keywords: *STEAM education, Inquiry-Based Learning (IBL), physics education, free fall, energy conservation, secondary education, Suriname.*

1. Introduction

In recent years, the integration of Science, Technology, Engineering, Art and Mathematics (STEAM) education has become increasingly important for addressing global challenges that demand innovative, adaptive, and problem-solving citizens. While countries with strong education systems have begun embedding STEAM principles into their curricula, many developing nations, including Suriname, are still in the early stages of this transformation. Suriname's secondary education system faces several barriers to meaningful science learning, including limited teacher training in active methodologies, a lack of interdisciplinary approaches, and a curriculum that often prioritizes rote learning over conceptual understanding.

Physics, particularly the topic of energy transformation during free fall, poses additional challenges. Although foundational for understanding mechanics and natural phenomena, the concept of energy remains highly abstract for many students. Misconceptions about potential and kinetic energy, and their interrelation, persist even at the upper secondary level

(Neumann *et al.*, 2013; Pramesti *et al.*, 2019). This calls for innovative teaching methods that go beyond transmission-based instruction.

This chapter presents findings from a case study conducted at the Henry N. Hassankhan School that explores the implementation of a STEAM-IBL instructional strategy grounded in inquiry-based learning (IBL). The intervention, implemented as a STEAM lesson to include artistic representation, investigates whether an integrated approach improves students' conceptual understanding of energy transformations in free fall, while also examining student engagement and teacher perceptions. By combining student-centered pedagogy with interdisciplinary content, the intervention seeks to bridge the gap between theoretical knowledge and real-life application. The chapter situates the study within broader discussions on curriculum innovation in Suriname, offering insights into how STEAM and IBL can support equitable, sustainable improvement in science education across similar educational contexts.

2. Theoretical Framework

This study is grounded in two interrelated theoretical domains: (a) the conceptual understanding of energy transformation in physics education, and (b) inquiry-based learning (IBL) as a pedagogical foundation for STEAM integration. Together, these frameworks support the design and evaluation of an instructional intervention aimed at improving student learning in the context of free fall.

2.1 Physics Education and the Concept of Energy in Free Fall

Energy is a central concept in physics but is often abstract and difficult for students to grasp. Research shows that students hold persistent misconceptions regarding energy conservation and transformation, particularly in dynamic systems such as free fall (Neumann *et al.*, 2013; Pramesti *et al.*, 2019). In free fall, the transformation of gravitational

potential energy into kinetic energy provides a fundamental example of mechanical energy conservation. Yet students frequently struggle to relate these transformations to observable phenomena or to quantify them correctly.

Studies at the secondary education level have shown recurring difficulties in this area. Students often define the system and its environment inadequately when analyzing energy transfer (Gandolfo *et al.*, 2024; Mosquera Lozano *et al.*, 2024), misapply the concepts of work and energy (Mera-Menéndez & López-González, 2023), and maintain the belief that the falling speed depends on the object's mass or shape (Sánchez Moreno *et al.*, 2023). They also tend to omit energy transfer processes in their explanations, limiting their ability to understand conservation comprehensively (Mosquera Lozano *et al.*, 2024). Importantly, these challenges are not restricted to secondary education: research with university students, both in engineering programs and introductory physics courses, confirms that similar misconceptions persist, manifesting as errors in calculating kinetic and potential energy, decontextualized use of formulas, and difficulties in interpreting graphical and geometric representations (Asnawi *et al.*, 2020; Escudero *et al.*, 2017; Aguilar *et al.*, 2007).

Teaching strategies that contextualize energy concepts through experimentation, modeling, and multiple representations have been shown to improve conceptual clarity (Podschuweit & Bernholt, 2018). In Suriname's multilingual and multicultural classrooms, these challenges may be compounded by language barriers and the abstract nature of scientific terminology. Grounding energy instruction in tangible, inquiry-driven activities therefore have the potential to facilitate better learning outcomes.

2.2. STEAM Education and Inquiry-Based Learning

STEAM education promotes the integration of disciplines in meaningful, real-world contexts, rather than teaching these disciplines in isolation (Li *et al.*, 2020). Effective STEAM instruction engages students with complex systems, predictions, data analysis, and design solutions.

These competencies are likewise central to IBL. In IBL, learners actively construct knowledge as they pose questions, conduct investigations, and reflect on outcomes (Pedaste *et al.*, 2015). Such learner-centered approaches have been associated with enhanced engagement, deeper conceptual understanding, and longer-term retention (Schunk, 2012; Huber, 2008).

The intersection between STEAM and IBL lies in their shared emphasis on authenticity, collaboration, and higher-order thinking. Leung (2020) highlights “boundary-crossing” pedagogy, wherein students negotiate meaning across disciplines using models, tools, or simulations as mediators. Similarly, it was found that mediating objects play a crucial role in supporting fluid movement between scientific and mathematical thinking (Hallström *et al.*, 2023; Bartolini, 2012), an essential competency in physics. Combining STEAM and IBL thus creates a learning environment where students engage in practice like those of scientists and engineers. Such environments are especially powerful in promoting equity and relevance in under-resourced educational contexts, as they leverage students' lived experiences as entry points into scientific reasoning (Fullan, 2016).

Grounded in this literature, we adopt a STEAM–IBL approach to teaching energy in free fall that targets persistent misconceptions and connects abstract formalisms to observable phenomena through low-cost experimentation, multiple representations, and brief reflective products. The aim is to deepen conceptual understanding while making learning active and locally meaningful in Surinamese secondary physics classrooms.

3. Methodology

This study employed a mixed-method, quasi-experimental design to compare a STEAM–IBL intervention with lecture-based instruction in two first-year lower-secondary physics classes. The intervention consisted of two 45-minute lessons on energy transformations during free fall, integrating guided experiments, small-group problem solving, and brief

arts-integrated reflections. The comparison group received teacher-centered explanations and textbook practice.

Learning outcomes were assessed using a validated pre/post-test designed to measure students' understanding of energy transformations during free fall.

Quantitative analyses included descriptive statistics, paired-sample t-tests within groups, and a one-way ANOVA to compare post-test scores across groups. Qualitative insights were obtained from a structured teacher reflection, which was analyzed thematically to triangulate the quantitative findings. To ensure rigor and ethical standards, the STEAM teacher completed 18 hours of professional development focused on IBL strategies.

3.1. Participants and Context

The study took place at Henry N. Hassankhan School, a general secondary school in Suriname. Two first-year lower-secondary physics classes participated: a STEAM-IBL section ($n = 15$) and a comparison class taught with a teacher-centered approach ($n = 13$). Students were 13–15 years old. Twelve additional students were excluded due to missing parental consent. Both classes followed the national physics curriculum and were taught by experienced physics teachers (different teachers for the two classes)

3.2. Instructional Design

The lesson was co-developed with input from university-level STEAM education experts and reviewed for disciplinary accuracy, pedagogical coherence, attention to diversity, and assessment alignment. Core elements are described in Figure 1.

Figure 1.1

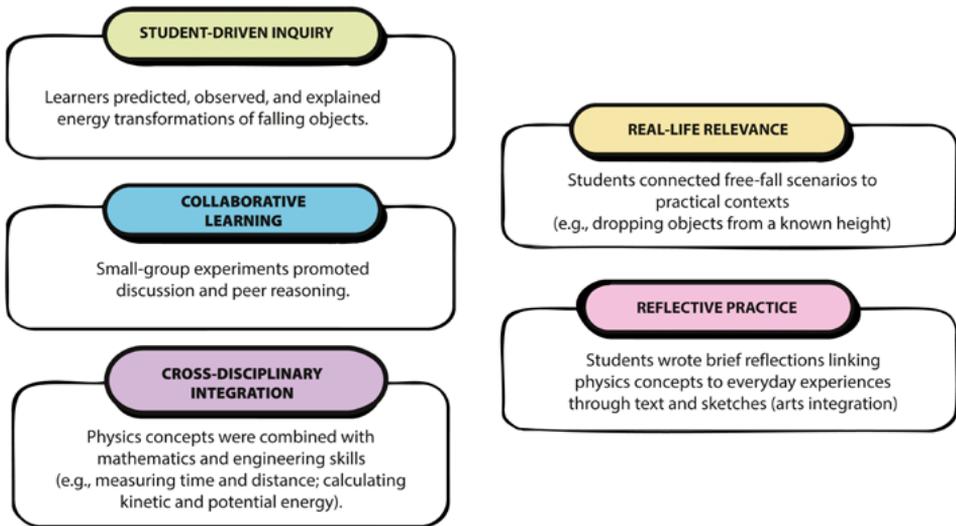


Figure 1. Core design principles of the sequence of two 45-minute STEAM-IBL lesson on free-fall energy and their alignment to assessment constructs.

The control group received conventional lecture-based instruction on the same topic, consisting of verbal explanations, worked examples from the textbook, and individual problem-solving, without experimental or collaborative activities. Prior to the study, the teacher implementing the STEAM approach completed an 18-hour professional development program focused on STEAM.

3.3. Assessment Instrument

Energy Concepts: Instrument design and validation

The assessment instrument consisted of 25 items, including multiple-choice, calculation, and open-ended questions, designed to measure students' understanding of free fall and energy transformations across different cognitive levels of Bloom's taxonomy. It addressed central concepts of

mechanics and energy in the secondary physics curriculum, organized into four thematic areas: (1) gravitational potential energy (dependence on mass and height, energy conservation), (2) kinetic energy and motion (velocity–energy relationships, formulas, and problem-solving), (3) free fall dynamics (acceleration due to gravity, motion without air resistance, conservation of mechanical energy), and (4) energy transformations and applications (conversion between potential and kinetic energy, real-life examples in sports, engineering, and safety). These categories were deliberately mapped to different levels of Bloom’s taxonomy, ensuring coverage from factual recall to conceptual understanding, application, analysis, evaluation, and creation.

A pre/post-test format was adopted, with a maximum raw score of 50 points distributed as follows: 19 multiple-choice items worth 1 point each (19 points), 2 numerical problems worth 9 points each (18 points), 3 open-ended reasoning questions worth 3 points each (9 points), and 1 short reflection item linking free fall to everyday life worth 4 points. For grading, raw scores were converted to a 0–10 scale by dividing the total by 5; for example, a raw score of 35 points corresponded to a final grade of 7.0. This normalization ensured comparability across items with different weights, simplified interpretation, and allowed scores to be reported on a standardized scale. A score of 10 indicated mastery of factual knowledge, conceptual understanding, and application of energy concepts in free fall, while lower scores indicated partial understanding or difficulty in applying these concepts to new contexts.

The instrument was reviewed and validated by a panel of subject-matter experts in physics education. For face validity, the reviewers examined the clarity of instructions, readability of items, and overall usability of the test, confirming that it was appropriate for secondary students. For content validity, they evaluated the alignment of items with the physics curriculum, the four thematic areas, and Bloom’s taxonomy levels, as well as the plausibility of distractors. Minor suggestions, such as improving wording and avoiding duplicate items, were incorporated into the final version. The expert panel concluded that the instrument was appropriate, reliable, and suitable for assessing students’ understanding of energy in free fall.

3.4. Data Collection and Analysis

The pre-test was administered two days before the intervention and the post-test one week after. All assessments were conducted under classroom supervision. Quantitative analyses included descriptive statistics (mean, standard deviation, minimum, and maximum), paired-sample t-tests to examine within-group changes, and a one-way ANOVA to compare post-test scores between groups. Significance was set at $p < 0.05$. Qualitative data were gathered via a structured teacher reflection form covering preparation, classroom execution, observed student responses, and suggested improvements; responses were analyzed thematically to triangulate the quantitative findings.

3.5. Ethical Considerations

Parental consent and student assent were obtained, anonymity was guaranteed, and participation had no effect on students' grades.

4. Research Questions

- RQ1. To what extent does a STEAM-IBL intervention improve students' conceptual understanding of energy transformations in free fall compared to traditional instruction?
- RQ2. How do the distributions of pre- and post-test scores differ between the STEAM and traditional groups?
- RQ3. What teacher-observed processes (engagement, collaboration, use of representations) accompany the intervention, and how do these observations help explain the quantitative results?

Expectation: Based on prior research on IBL and integrated STEAM pedagogy, we anticipated greater mean gains in the STEAM group (Li *et al.*, 2020; Pedaste *et al.*, 2015), with variability patterns explored empirically.

4.1 Student Learning Gains

Both groups improved from pre- to post-test, with the STEAM group showing the larger average gain. Table 1 summarizes mean scores (10-point scale) and average improvements.

Table 1.1 Average test score improvements by group (10-point scale)

<i>Group</i>	<i>n</i>	<i>Mean Pre-Test</i>	<i>Mean Post-test</i>	<i>Mean Gain</i>
Traditional	13	2.2	3.2	+1.0
STEAM	15	1.9	4.3	+2.4

To illustrate individual progress, nearly all students in the STEAM group improved, with several showing large gains. In contrast, improvement in the traditional group was less consistent across individuals.

4.2. Descriptive Statistics

A fuller statistical summary (means, standard deviations, and range) appears in Table 2. While both groups improved, the STEAM group exhibited a wider post-test range, suggesting greater individual variation.

Post-test distributions were positively skewed in both groups, indicating that a subset of students performed substantially above their group's central tendency. The STEAM group's higher post-test variance is consistent with the presence of several high-gain learners.

Table 1.2 Descriptive statistics of test scores (10-point scale)

<i>Group</i>	<i>Test</i>	<i>Mean</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
STEAM	Pre-test	1.9	0.62	1.0	3.0
STEAM	Post-test	4.3	2.00	2.2	7.8

<i>Group</i>	<i>Test</i>	<i>Mean</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
Traditional	Pre-test	2.2	0.61	1.0	3.2
Traditional	Post-test	3.2	1.50	1.6	7.0

4.3. Statistical Testing

Inferential tests corroborated the descriptive findings. A paired-sample t-test showed a statistically significant pre-to-post gain in the STEAM group ($p = 0.000016$), while gains in the traditional group did not reach significance ($p = 0.06176$). A one-way ANOVA comparing post-test scores across groups yielded a significant effect, $F(1, 26) = 20.84$, $p < 0.001$, indicating a clear advantage for the STEAM-IBL instruction. The effectiveness of this approach was evaluated by comparing pre-test and post-test scores of students in the STEAM group and the traditional group.

Table 1.3 Comparison of results in the two groups

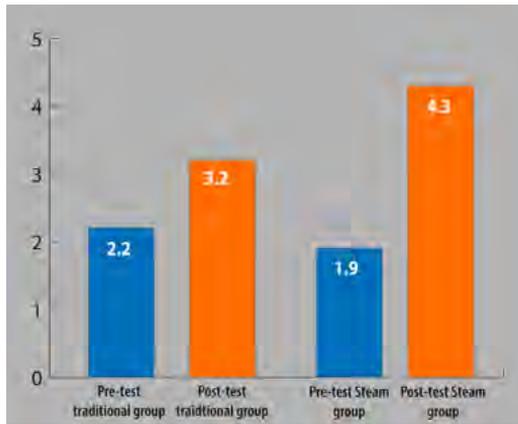
<i>Value</i>	<i>STEAM Group (n = 15)</i>	<i>Traditional Group (n = 13)</i>
Pre-test scores	1.0 - 3.0	1 - 3.2
Pre-test average	1.89	2.17
Post-test scores	2.2 - 7.8	1.6 - 7.0
Post-test average	4.33	3.15

Table 3 shows the comparative analysis that revealed that students in the STEAM group achieved a substantially greater improvement in their understanding of energy in free fall compared to those in the traditional group. While both groups showed positive changes from pre- to post-test, the STEAM intervention resulted in an average gain of +2.44 points, more than double the +0.98 points observed in the traditional group. This suggests that inquiry-based, hands-on strategies within the STEAM framework not only facilitated higher learning gains but also promoted a deeper conceptual grasp of the topic, whereas the traditional instruction led to more modest improvements.

Table 1.4 Summary Table of Scores

<i>Group</i>	<i>n</i>	<i>Pre-test (Mean ± SD)</i>	<i>Post-test (Mean ± SD)</i>	<i>Improvement (Mean)</i>
STEAM Group	$\frac{1}{5}$	1.89 ± 1.62	4.33 ± 1.62	+2.4
Traditional Group	$\frac{1}{3}$	2.17 ± 0.67	3.15 ± 1.61	+0.98

Figure 1.2. Average Scores Comparison – compares the average pre-test and post-test scores between the STEAM and Traditional groups.



Interpretation

The results indicate that students in the STEAM group achieved significantly higher learning gains compared to the traditional group. The substantial increase in post-test scores for the STEAM group suggests that integrating inquiry-based learning with STEAM activities effectively enhanced students’ understanding of energy in free fall. In contrast, students in the traditional group showed modest improvement, demonstrating the comparative advantage of the STEAM approach in promoting conceptual learning.

Individual student pre-and post-test scores for each group.

Figure 1.3. Traditional Group–shows each student's pre-test and post-test scores.

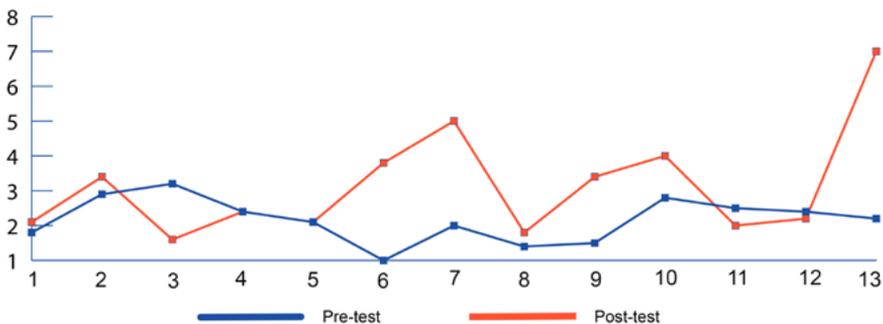
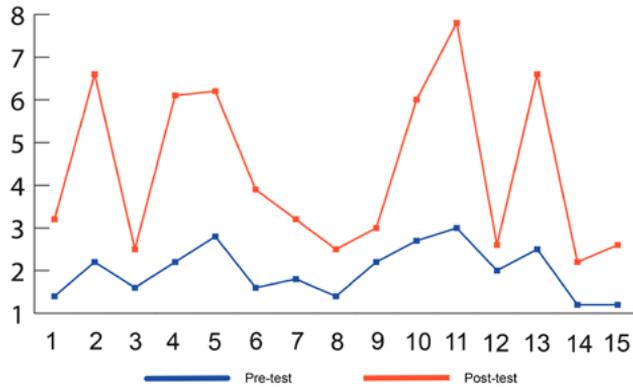


Figure 1.4. STEAM Group—shows each student's pre-test and post-test scores.

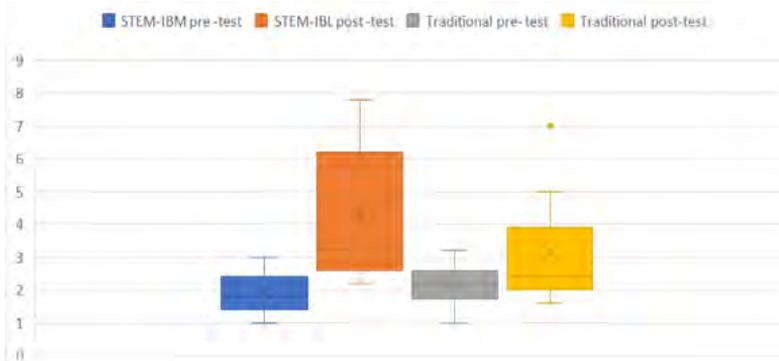


The graphs clearly highlight the improvement in the STEAM group, especially compared to the Traditional group.

4.4. Score Distribution and Variability

The STEAM group's distribution was broader at post-test, with some students achieving large improvements (~3.0 → ~7.8). Large individual gains also occurred in the traditional group (~2.2 → ~7.0); however, these appeared as isolated cases rather than part of a consistent pattern across the group. These patterns suggest that while both approaches can support high achievers, the STEAM intervention yielded more widespread improvement.

Figure 1.5. Boxplot of Pre- and Post-test Scores for STEAM and Traditional Groups.



4.5. Teacher Reflections

The teacher's structured reflection provided qualitative insights that reinforced the quantitative outcomes. A shift in roles was emphasized: "*The teacher is not considered the source of information but as a coach,*" alongside students' enthusiasm: "*They loved the group discussions.*" The teacher also identified challenges, particularly "*Time management when it came to group discussion,*" and highlighted the need for technological support: "*If I had access to a simulation, it would have helped visualize the transformation of energy more clearly.*"

Overall, the teacher expressed a strong intention to continue using inquiry-based strategies and outlined key conditions for scaling up the approach. These included targeted teacher professional development, access to simple and affordable simulations, and alignment with the existing curriculum to support sustainable implementation in diverse classroom contexts. In terms of broader implications, the study suggests that such approaches are feasible in resource-constrained settings and hold potential for scale-up when these conditions are addressed.

5. Discussion

The findings provide evidence that implementing a STEAM-IBL can enhance students' conceptual understanding of energy transformations during free fall. While both groups improved, the gains in the STEAM group were larger and statistically significant, supporting prior work on inquiry-driven and interdisciplinary teaching (Pedaste *et al.*, 2015; Li *et al.*, 2020).

A notable difference between groups concerns the consistency of improvement. The STEAM group showed broader participation in learning gains, whereas the traditional group displayed uneven progress, with a few students achieving substantial increases and several showing minimal change. Large individual gains occurred in both groups, but in the STEAM group they were embedded within a wider pattern of growth. This suggests that, relative to traditional instruction, a STEAM-IBL approach may offer a more equitable platform for learning across a heterogeneous class.

The teacher's reflections reinforce these interpretations. A shift from knowledge transmission to facilitation coincided with increased student questioning, hands-on measurement, and meaningful connections between equations and actions, mechanisms known to promote conceptual change (Podschuweit, S., Bernholt, S.; Schunk, 2012). Challenges, time management and limited access to technology, indicate the need for instructional scaffolds (structured roles, timing protocols) and resources (simulations) to support all learners. These insights align with arguments that sustainable educational change requires coherence among pedagogy, resources, and teacher learning (Fullan, 2016).

The broader post-test variance in the STEAM group suggests differentiated impacts. Differences in prior knowledge, readiness for collaborative inquiry, or comfort with experimentation likely contributed to variability (Neumann *et al.*, 2013). Future iterations should incorporate tiered supports (worked examples, sentence starters for explanations, targeted mini-lessons) and structured collaboration to ensure that students with lower prior knowledge benefit as fully as their peers. From a Surinamese perspective, where curricula remain largely traditional and exam-oriented, this case study demonstrates that even a single, well-designed STEAM-IBL lesson can produce measurable learning benefits and richer engagement. Scaling will require investments in teacher professional development, curricular materials, and technologies that enable modeling and visualization.

Finally, the study contributes to international evidence that inquiry-based STEAM education can be effective in under-resourced contexts when thoughtfully adapted to local realities (Hallström *et al.*, 2023; Leung, 2020; Bartolini, 2012). It shows that student-centered, interdisciplinary teaching can be viable and impactful in multilingual classrooms, provided teachers are supported with time, training, and tools.

6. Conclusions

This study investigated the impact of a STEAM-IBL instructional strategy on students' understanding of energy transformations during free fall in Surinamese secondary education. The STEAM group achieved significantly

greater learning gains than the traditional group, alongside positive shifts in engagement and participation. Teacher reflections corroborated these outcomes, highlighting increased student agency and the value of hands-on measurement and multiple representations.

An important pattern concerned equity: the STEAM intervention produced broader gains across the class, whereas the traditional approach yielded uneven outcomes shaped by a few high-gain individuals. At the same time, variability within the STEAM group indicates that some learners require additional scaffolding, particularly those less accustomed to inquiry or with lower prior knowledge. Practical challenges (group management, limited technology) underscore the necessity of sustained teacher support.

Despite these constraints, the study represents a pioneering attempt to integrate STEAM and IBL into physics education in Suriname. The results suggest that such approaches can address persistent misconceptions about energy while making physics more meaningful. To scale these benefits, future efforts should prioritize teacher professional development, curriculum innovation, and access to appropriate learning technologies (simulations and data-collection tools). These steps are crucial for preparing Surinamese students to meet the demands of a rapidly changing, knowledge-based world.

Ethical Statement

The authors declare that, in preparing this manuscript, digital tools such as Grammarly Premium (for spelling, grammar, and style corrections) and ChatGPT (OpenAI) (for writing suggestions and support in structuring ideas) were used. These tools served solely as linguistic and clarity aids, under the authors' supervision and critical judgment.

At no point did these tools replace the intellectual work, interpretation of results, or scientific analysis; all content decisions, discussions, and interpretations were conducted by the authors.

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