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World Journal of Applied Physics
2025, Vol. 10, No. 3, pp. 68-77
https://doi.org/10.11648/j.wjap.20251003.12

Review Article

Enhancing Physics Teachers' Practices Through Problem-based Learning in Uganda Secondary Schools

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Abstract

The study assessed the impact of aligning teaching practices with reformed pedagogical principles when problem-based learning was implemented in a physics class at lower secondary schools in Sheema District, Western Uganda. The research focused on understanding how teaching practices evolved and aligned with contemporary educational reforms when PBL was introduced as a teaching method. Method: Teachers in the treatment group were first trained in the PBL method by Lecturers from the National Teacher College, who were specifically hired for this purpose. The training sessions aimed to equip teachers with the necessary knowledge and skills to implement PBL effectively in their classrooms. These lecturers provided continuous support to the teachers, guiding them in developing schemes of work, detailed lesson plans, relevant instructional materials, and strategies for delivering PBL-based physics lessons. To evaluate the implementation process, the researcher, together with trained assistants, conducted lesson observations using the Reformed Teaching Observation Protocol (RTOP). This protocol is designed to measure the extent to which teaching practices align with reformed pedagogical principles. Findings: The study revealed an overall positive alignment with reformed teaching practices, as indicated by a mean RTOP score of 79.625%. This score reflects a significant improvement in teaching practices among teachers who adopted PBL, suggesting that the method is interactive, student-centered, and inquiry-based. The findings highlight that the Ugandan physics classrooms, particularly in Sheema District, are capable of embracing reformed teaching practices that can lead to enhanced teaching and learning experiences. Recommendation: Based on these findings, it is recommended that teachers continue to use PBL as a primary teaching method in physics. The adoption of PBL aligns teaching practices with reformed educational principles and also has the potential to improve students' academic achievement and overall learning outcomes. Additionally, ongoing professional development opportunities should be provided for teachers to sustain and deepen their understanding and application of PBL.

Keywords

Reformed Teaching, Simple Machine, Problem-Based Learning, Physics Class

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Received: 23 December 2024; **Accepted:** 6 January 2025; **Published:** 15 September 2025

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1. Introduction

Education in Uganda, like in many parts of the world, is continually evolving to meet the demands of the 21st century. In the pursuit of fostering innovative and effective teaching methods, the realm of science education has witnessed a shift towards reformed pedagogical approaches [1]. One such approach, Problem-Based Learning (PBL), has gained prominence for its ability to engage students in active learning and problem-solving, thus enhancing their understanding of complex scientific concepts. In the context of Ugandan classrooms, where the teaching of science subjects remains pivotal, this study examines the reform of teaching simple machines to Form 2 students. Simple machines are fundamental to physics and engineering principles and serve as a foundational topic in the physics curriculum. However, non-PBL methods often fall short of capturing the students' interest and fostering deep conceptual understanding. In response to these challenges, the incorporation of PBL presents a promising avenue for transforming the teaching of simple machines [2]. This approach encourages active participation to make abstract scientific concepts more understandable to students.

Science education in Uganda has undergone several transformations over the years. The reforms in the curriculum and teaching methods have been introduced to enhance the quality of education and align it with global standards. These historical developments set the stage for exploring innovative teaching practices such as PBL [3]. Reformed teaching practices represent a significant departure from traditional methods of instruction to learner-centered methods [4] . The method promotes active learning, problem-solving, and deep engagement with the subject matter. These principles are deeply rooted in educational theories such as constructivism and align with contemporary pedagogical goals [5].

Reformed teaching practices recognize that passive reception of information is less effective in promoting true understanding and retention of knowledge [6-8]. Instead, students should be actively involved in the learning process. They engage with the content, ask questions, and seek solutions to real-world problems. Through active learning, students become co-creators of knowledge rather than passive recipients of information.

Reformed teaching involves the cultivation of critical thinking skills [9, 10], encouraging students to analyze, evaluate, and synthesize information. They learn to question assumptions, consider alternative perspectives, and make informed judgments. Thinking enhances subject-specific knowledge and equips students with invaluable skills applicable to various aspects of their lives [11]. It places a strong emphasis on inquiry-based learning [12, 13] and problem-solving. Instead of memorizing facts, students explore topics through inquiry, posing questions, and seeking answers. They are presented with authentic, real-world problems that require them to apply their knowledge and problem-solving skills [14, 15].

This approach deepens their understanding and prepares them for the challenges they may encounter in their professional journeys. At the heart of reformed teaching is the belief that students construct their understanding of concepts. Rather than merely absorbing information from lectures, students actively construct knowledge through exploration and discovery [15]. This process of constructing meaning is personal, leading to more lasting and transferable learning outcomes. These principles collectively form the foundation of effective science education. They align with contemporary educational goals that prioritize the development of skills and competencies essential for success in the modern world [16, 17]. Reformed teaching stimulates scientific knowledge and equips students with the ability to think critically, solve complex problems, and adapt to evolving scientific paradigms.

For the context of teaching simple machines in Ugandan classrooms, the adoption of reformed teaching practices holds promise for making abstract scientific concepts more accessible and engaging for students. The integration of PBL aligns with these principles, fostering a dynamic and student-centered learning environment that encourages active exploration and deep understanding. The integration of PBL in physics education has demonstrated notable effectiveness. This combination creates a holistic and engaging learning experience for students. PBL, with its emphasis on active learning, critical thinking, and collaborative problem-solving, sets the stage for a dynamic educational approach [18, 19]. Students are presented with real-world problems, sparking their curiosity and encouraging them to explore solutions independently or in groups. However, the impact of PBL offers a vast repository of visual content [20] that aligns seamlessly with the objectives of PBL. Concepts related to simple machines [21], often abstract and challenging to grasp solely through traditional methods, come to life through demonstrations, animations, and real-world examples. This inclusivity ensures that students with varying preferences and strengths can benefit from the combined approach. Moreover, allowing students to revisit and reinforce their understanding as needed promotes self-directed learning [22]. Students enjoy the application of scientific principles in action to connect theory and practice, which fosters a deeper and more enduring understanding of the subject matter [23]. This diversity of resources enriches students' learning experiences, providing them with a global perspective on science.

This study aims to bridge existing research gaps by investigating the integration of PBL in teaching simple machines in Ugandan classrooms. This study was guided by the social constructivism theory [24]. The theoretical framework of social constructivism provides the philosophical underpinning for reformed teaching practices [25].

At its core, social constructivism posits that individuals actively construct knowledge through interactions with their environment and peers. In this context, the teacher becomes a facilitator who provides guidance and support to students [26]. Moreover, the theory acknowledges the impact of cultural and contextual factors on learning [27], which is particularly relevant in the Ugandan educational context. Therefore, the study's approach integrates relevant cultural elements to make the learning experience more relatable and meaningful for students. Overall, social constructivism offers a robust theoretical foundation for understanding how the integration of PBL can enhance the teaching of simple machines in Ugandan classrooms by actively involving students in the construction of knowledge within a social and collaborative learning environment.

2. Aim

To assess the impact of problem-based learning on teaching practices in physics at lower secondary schools in Sheema District in Uganda.

How do teachers' PBL practices enhance the learning of physics in secondary schools?

3. Research Ethical Clearance

The research project underwent an internal collegial ethical process and adhered to the ethical standards and principles of the University of Rwanda College of Education (CE/078/EN/GI/2021). While in Uganda, Ethical clearance was sought from the Mbarara University of Science and Technology Research Ethics Committee (MUST-2021-307), which forwarded it to the Uganda National Council of Science and Technology for Final approval (SS1304ES). Permission (Permission letter ref. ADM/97/298/01) to access the schools was obtained from the Ministry of Education and Sports, Office of the Permanent Secretary (PS), who wrote to the Chief Administrative Officer (CAO) with copies to the District Education Officer (DEO) and Resident District Commissioner (RDC) to provide the necessary support for the study. With permission from the CAO, the DEO wrote to school heads and informed them about the research study. The school heads responded positively and even sent their physics teachers who teach Form Two to attend a three-day training on how to use Problem-Based Learning (PBL). Some days after the training of the treatment group, a briefing was held for students, physics teachers, and school administrators at their respective schools to discuss what the intervention would entail.

3.1. Use of Reformed Teaching Observational Protocol

The researcher and assistant read the RTOP Training Manual and observed several physics class videos to calculate reliability. Reliability is defined as the extent to which different methods arrive at the same interpretation or result. Inter-observer reliability is the consistency between two or more observers of the same construct. The rate agreement was calculated.

Rate agreement = number of agreements between two (2) observers/ total number of possible constructs. Inter-reliability coefficients among two observers after watching the first video were: 0.64 and 0.65. While from watching the second video, the agreement rate was below 6. RTOP statements were revised and discussed, considering the first and second videos. In the third video, reliability was assessed between observers, yielding coefficients of 0.89 and 0.88. These are considered high-reliability coefficients. To remove agreement due to chance, Cohen's Kappa Coefficient of inter-observer agreement was computed.

Cohen's Kappa = (OA-AC)/(1-AC), where; OA- is the rate of agreement between observers,

AC- Is the inter-observer agreement rate due to chance; the sum of disagreements between observers (Observer-1only and Observer-2 only), we found 0.75 and 0.84 of Kappa across the observers. Cohen's Kappa coefficients range from 0 (insufficient agreement due to chance) up to the maximum value of perfect agreement between observers. Values below 0.4 indicate poor agreement; 0.7 is the minimum acceptable level, while greater than 0.75 indicates excellent agreement.

3.2. Lesson Observation

Lessons conducted by the teachers in the treatment group (PBL) were assessed by well-trained lesson observers using a reformed teaching observation protocol (RTOP) while teaching the students. During lesson observation, classroom activities were recorded in the form of notes. Then, each observer filled in the rest of the protocol using the notes compiled during the lesson's progress. Four (4) teachers were observed teaching physics classes on simple machines. A total of 6 Lessons were observed. Teacher-1 from school-1 was observed in Class A and Class B, Teacher-2 from school-2 was also observed in Class A and Class B, Teacher-3 was observed in one class, and Teacher-4 was observed in one class, as shown in the table.

Table 1. *Live lessons were observed from four selected schools.*

Teachers	Schools	Class A	Class B	No. of Lessons
1	Private	Lesson 1	Lesson 1	2
2	Government	Lesson 1	Lesson 1	2
3	Private	Lesson 1		1
4	Government	Lesson 1		1
				Total = 6 lessons

Lesson observation was conducted to determine whether the teachers were able to utilize PBL effectively. Classroom observation data were collected using the standardized Reformed Teaching Observation Protocol (RTOP) developed by Piburn and Sawada, which is available at: https://www.physport.org/assessment.cfm?A=RTOP.

was validated by the facilitation group of the Arizona Collaborative for Excellence in the preparation of teachers. It was externally validated by Sawada and internally assessed by Piburn. The facilitation group included Kathleen Falconer, Jeff Turley, Russel Benford, and Irene Bloom. RTOP has proven its validity and reliability across the globe, with the potential to reveal reformed teaching during the implementation of the new method. The background information includes the subject observed, grade level, observation name, date of observation, start and end of observation, and lesson title. The grading has three themes: lesson design and implementation, content, and classroom culture. The sub-themes include lesson design and implementation (similar to the theme), proportional knowledge, procedural knowledge, communicative interaction, and student/teacher relationship. These themes are divided into five sub-themes, and each item is evaluated on a 5-scale. The scales reflect how the lesson and its characteristics are observed. Possible scores range from 0 to 100 points. The higher scores correspond to a greater degree of the reform.

During classroom observation, the researcher and his assistant entered the classroom and secured a quiet place where they could see and hear both the teacher and students clearly without disrupting the lesson. Each observer had a printed RTOP scoring sheet reflecting the RTOP framework details (lesson design and implementation, content-propositional knowledge, procedural knowledge, classroom culture-communicative interactions, and student/teacher relationships). Each item was scored on a scale from 0 to 4, where 0 means the feature was not observed, and 4 means it was very strongly present. As the lesson progressed, the researcher and his assistant carefully observed and took notes following the RTOP framework. At the end, the researcher and his assistant compared their scores, discussed any differences, and reached a consensus. This helped to improve the reliability of the observation data. The completed RTOP score reflected the extent to which the teacher used student-centred methods during key elements of problem-based learning.

Microsoft Excel was used to record all data gathered during class observations. The RTOP data was used for analysis. Mean scores were calculated on an Excel sheet column under each scale and an Excel sheet row, along with each statement. We computed average learner-centredness for all observed lessons.

4. Analysis

Data analysis was conducted using MS Excel 2016. The average score and standard deviation for all observations were computed along each of the 25 RTOP statements. Each score was divided by the maximum score (4) and multiplied by 100 to obtain a percent score. The overall results are presented in Table 2. The average score for each of the five RTOP themes or components was simplified and presented in Figure 1. Finally, the average score for each teacher was calculated and presented in Figure 2.

5. Findings

The findings of the study are presented based on the Reformed Teaching Observation Protocol (RTOP) components, which assess the effectiveness of teaching practices in a Ugandan physics classroom. Table 2 presents the percent mean score and standard deviation for all 25 RTOP practices.

Table 2. *Ugandan Physics Classroom Reformed Teaching Scores.*

RTOP Components	RTOP Statements	Average score (%)	SD %
Lesson design and implementation	Lesson design and implementation		
1	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein	85.42	12.59
2	The lesson was designed to engage students as members of a learning community	82.29	11.61
3	In this lesson, student exploration preceded the formal presentation	80.21	12.72
4	This lesson encouraged students to seek and value alternative modes of investigation or of problem-solving	81.25	11.06
5	The focus and direction of the lesson were often determined by ideas originating from students	80.21	10.37
Content	Propositional knowledge		
6	The lesson involved fundamental concepts of the subject	84.38	12.36
7	The lesson promoted strongly coherent conceptual understanding	80.21	10.37
8	The teacher had a solid grasp of the subject matter content inherent in the lesson	80.21	10.37
9	Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so	77.08	10.21
10	Connections with other content disciplines and/or real-world phenomena were explored and valued	75.00	10.43
Content	Procedural knowledge		
11	Students used a variety of means (models, drawings, graphs, concrete materials, manipulative, etc.) to represent phenomena	80.21	14.71
12	Students made predictions, estimations, and/or hypotheses and devised means for testing them	75.00	12.77
13	Students were actively engaged in thought-provoking activities that often involved the critical assessment of procedures	78.13	11.21
14	Students were reflective about their learning	79.17	9.52
15	Intellectual rigor, constructive criticism, and the challenging of ideas were valued	79.17	9.52
Classroom culture	Communicative interaction		
16	Students were involved in the communication of their ideas to others using a variety of means and media	83.33	12.04
17	The teacher's questions triggered divergent modes of thinking	81.25	11.06
18	There was a high proportion of student talk and a significant amount of it occurred between and among students	79.17	9.52
19	Student questions and comments often determined the focus and direction of classroom discourse	80.21	10.37
20	There was a climate of respect for what others had to say	75.00	10.43
Classroom culture	Student/Teacher Relationships		
21	Active participation of students was encouraged and valued	83.33	12.04
22	Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence	77.08	7.06

RTOP Components	RTOP Statements	Average score (%)	SD %
23	In general, the teacher was patient with students	79.17	9.52
24	The teacher acted as a resource person, working to support and enhance student investigations	78.13	8.45
25	The metaphor "teacher as listener" was very characteristic of this classroom	76.04	5.10

In the category of Lesson Design and Implementation, it is evident that the instructional strategies and activities in the classroom respect students' prior knowledge and preconceptions, with an average score of 85.42%. Moreover, the lesson design successfully engages students as members of a learning community 82.29%. Student exploration precedes formal presentation, encouraging active participation at 80.21%. The classroom environment also values alternative modes of investigation and problem-solving at 81.25%, with the focus often driven by students' ideas at 80.21%.

The content aspect of Propositional Knowledge indicates that the lesson effectively incorporates fundamental concepts of the subject, 84.38%. It promotes strongly coherent conceptual understanding 80.21% and is delivered by a teacher with a solid grasp of the subject matter content 80.21%. However, there is room for improvement in encouraging elements of abstraction, 77.08%, and exploring connections with other content disciplines and real-world phenomena 75.00%,

Regarding Procedural Knowledge, students are encouraged to use various means to represent phenomena 80.21%. They make predictions, estimations, and hypotheses with means for testing them at 75.00%. The classroom fosters active engagement in thought-provoking activities that often involve critical assessment of procedures 78.13%. Students also demonstrate a reflective approach to their learning, 79.17% and value intellectual rigor, constructive criticism, and challenging of ideas, 79.17%.

In terms of Communicative Interaction, students are actively involved in the communication of their ideas using various means and media, 83.33%, and the teacher's questions trigger divergent modes of thinking, 81.25%. There is a high proportion of student talk, with substantial discussion occurring between and among students, 79.17%. Furthermore, student questions and comments often determine the focus and direction of classroom discourse 80.21%. A climate of respect for others' contributions is maintained at 75.00%.

Regarding Student/Teacher Relationships, the active participation of students is encouraged and valued at 83.33%. Students are also encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence 77.08%. The teacher exhibits patience with students 79.17% and acts as a resource person to support and enhance student investigations 78.13%. The metaphor "teacher as a listener" is characteristic of this classroom 76.04%,

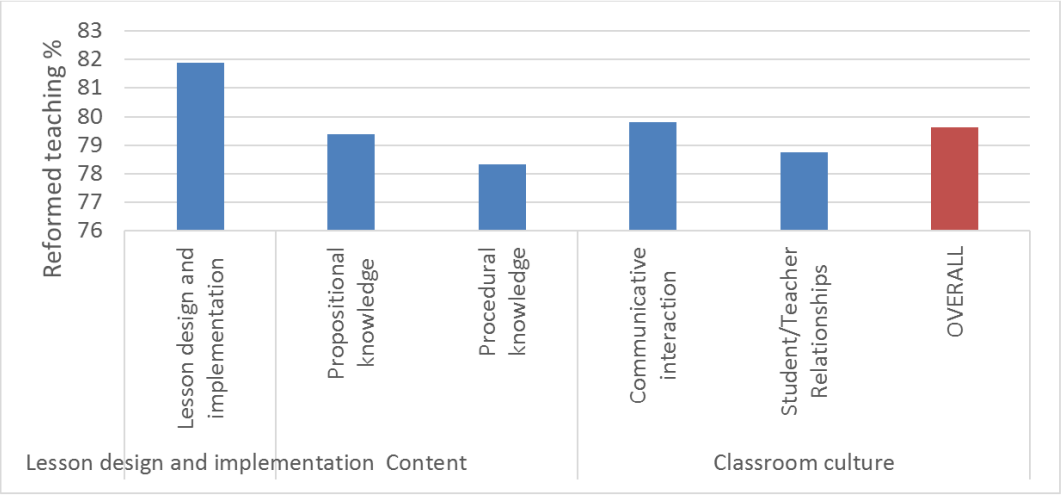

Figure 1. *Reformed teaching percentage of classroom activities during PBL instruction.*

Figure 1 presents mean (average) scores and standard deviations (SD) for each component of the Reformed Teaching Observation Protocol (RTOP) in a Ugandan physics classroom. In Lesson Design and Implementation, the mean score

was 81.875% with an SD of 11.670%. For Content - Propositional Knowledge, the mean score was 79.375% with an SD of 10.748%, while Content - Procedural Knowledge had a mean score of 78.333% with an SD of 11.544%. In Classroom Culture - Communicative Interaction, the mean score was 79.792% with an SD of 10.682%, and Classroom Culture - Student/Teacher Relationships had a mean score of 78.750% with an SD of 8.433%. The Overall Assessment yielded a mean score of 79.625% with an SD of 10.615%. These scores collectively indicate that the teaching practices in the Ugandan physics classroom generally align with reformed teaching principles, although some variations exist across components, suggesting opportunities for both strengths and improvements in physics education.

The mean scores for teaching practices across different schools and teachers are presented in Figure 2. Teacher 1 from School 1 achieved a mean score of 3.19 (79.83%), Teacher 2 from School 2 attained a mean score of 3.14 (78.5%), Teacher 3 from School 3 had a mean score of 3.25 (81.33%), and Teacher 4 from School 4 received a mean score of 3.15 (78.83%). The overall mean score across all teachers and schools was 3.185, equivalent to 79.625%. These scores indicate the effectiveness of teaching practices among different teachers and schools, with variations in performance but an overall alignment with reformed teaching principles.

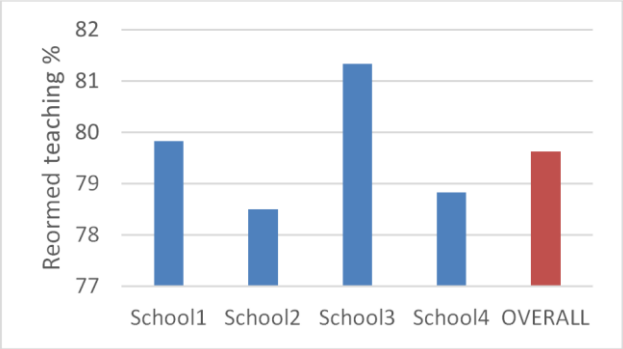

Figure 2. *Teaching in schools: 1&3 are Private;2&4 are Public.*

6. Discussion

The findings of the study, as assessed using the RTOP components, provide valuable insights into the effectiveness of reformed teaching practices in Ugandan physics classrooms. This in-depth analysis of the RTOP components highlights the effectiveness of teaching practices and serves as a foundation for future researchers and educational policies, fostering continuous improvement in Ugandan physics education.

The positive outcomes observed in this study can be attributed to the effective implementation of reformed teaching practices in Ugandan physics classrooms. In addition, the analysis of class interaction and students' engagement levels alongside the feedback from teachers and students gives evidence that positive outcomes witnessed in this study are a direct result of the thoughtful and skillful integration of reformed teaching methods. This highlights their pivotal role in evaluating the overall learning experience in Ugandan classrooms.

Several factors contribute to these results:

The emphasis on respecting students' prior knowledge and preconceptions (85.42%) creates a supportive learning environment. Acknowledging what students already know and building upon it encourages active engagement and confidence in their abilities [28, 29]. Student-Centered Learning: The design of lessons that engage students as members of a learning community (82.29%) fosters collaboration and shared responsibility for learning. This student-centered approach motivates learners to take an active role in their education [30]. The promotion of student exploration before formal presentation (80.21%) aligns with the principles of problem-based learning (PBL). This approach allows students to discover concepts through practical experience, enhancing their understanding [22, 26].

The encouragement of students to seek alternative modes of investigation or problem-solving (81.25%) nurtures critical thinking and creativity. It empowers students to approach challenges from various angles, promoting intellectual growth [31-33]. Student Input: Allowing the focus and direction of the lesson to be determined by students' ideas (80.21%) gives students a sense of ownership over their learning. It taps into their curiosity and encourages active participation [34].

The findings of this study carry significant implications for physics education in Uganda. These include:

The effective implementation of teaching practices has the potential to lead to improved learning outcomes among students [35]. When students are actively engaged in their learning, they are more likely to grasp complex concepts and retain knowledge [14, 36].

Encouraging students to explore alternative modes of investigation and problem-solving fosters critical thinking skills. These skills are valuable not only in physics but also in various aspects of life and future careers.

The student-centered approach and active classroom participation promote higher levels of student engagement [37, 38]. Engaged students are more likely to be motivated and enthusiastic about their studies. These findings underscore the importance of teacher training in reformed teaching practices [19]. Teachers who are well-equipped to implement these methods can create more effective learning environments.

The study's findings align with the theoretical framework of social constructivism. Social constructivism posits that learning is a social process where individuals actively construct knowledge through interaction with their environment and peers [39]. In the context of this study, the emphasis on student engagement, collaboration, and critical thinking reflects the principles of social constructivism. The theoretical response to these findings involves recog-

nizing that learning is not a passive absorption of information but an active process of knowledge construction [40]. Reformed teaching practices prioritize active learning [6], critical thinking [41], and student engagement [42], which are central tenets of social constructivism. Therefore, these practices align with the theoretical underpinnings of effective science education.

The success of this study, where every RTOP statement received scores above 50% and where every teacher scored above 50% in all RTOP statements, can be attributed to the innovative intervention that combined PBL. This approach effectively bridged potential gaps in traditional teaching methods by fostering active student engagement [6, 8], providing accessible learning resources, facilitating visual and experiential learning, offering flexibility in learning, reinforcing problem-solving skills, enhancing teacher-student interaction, and catering to diverse learning styles. this intervention created a dynamic and inclusive learning environment, ultimately leading to the positive outcomes observed in the study. This approach holds promise for physics education in Uganda and also as a model for modernizing and enriching science education globally.

7. Conclusion and Limitations

The study examined the reformed teaching-learning practices due to Problem-Based Learning (PBL) in Ugandan physics classrooms using the Reformed Teaching Observation Protocol (RTOP). The overall mean score for reformed teaching across the observed classrooms was 79.625%. Teacher-specific mean scores ranged from 78.5% to 81.33%. While the findings indicate a generally positive alignment with reformed teaching principles, some variability exists among teachers and schools. The variation may be due to the different school cultures of teachers and students. Also, teachers who are due to retire are resistant to change. The findings provide valuable insights into the impact of the teaching and can inform strategies for enhancing the quality of physics education in Ugandan classrooms. The study suggests that reformed teaching practices are effectively implemented in Ugandan physics classrooms, fostering student engagement, critical thinking, and collaborative learning. The variations in scores among teachers and schools highlight the need for targeted professional development and support for educators who may benefit from enhancing their reformed teaching strategies.

The focus on student exploration, communicative interaction, and student-teacher relationships creates positive classroom environments conducive to effective learning. The study's limited sample size may not fully represent the diversity of teaching practices across all Ugandan schools, indicating the need for more extensive research involving a broader range of institutions. The absence of a quasi-experimental study comparing PBL to traditional methods restricts the ability to conclusively determine the impact of this teaching approach on student outcomes. Future research should address this limitation to provide more comprehensive insights into the effectiveness of PBL. The study recommends providing ongoing professional development opportunities for teachers to develop reformed teaching skills further, and encourage collaboration and peer learning among teachers to share effective strategies and experiences in implementing reformed teaching practices.

Abbreviations

RTOP	Reformed Teaching Observation Protocol
PBL	Problem-Based Learning
NTC	National Teachers' College
SD	Standard Deviation

Acknowledgments

The African Centre of Excellence for Innovative Teaching and Learning Mathematics and Sciences (ACEITLMS) research fund helped me conduct the study. Enabel-Uganda for contributing part of the tuition to the corresponding author. The Ministry of Education and Sports, Uganda, for granting permission to access the schools for the study. Also, school administrators, Teachers, Students, Colleagues, and friends are highly appreciated. National Teacher Colleges lecturers for their support in training.

Author Contributions

Nicholus Gumisirizah: Conceptualization, Resources, Funding Acquisition, Investigation, Methodology, Writing-Original draft, Writing -review & editing, Analysis, software

Joseph Nzabahimana: Conceptualization, Supervision, Visualization, Validation, Visualization

Charles Magoba Muwonge: Conceptualization, Data Curation, Validation, Supervision, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

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