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PROJECT-BASED LEARNING USING BIOMASS STOVES: ENHANCING ENERGY CONCEPT UNDERSTANDING, LEARNER COMPETENCES, AND COMMUNITY ENGAGEMENT IN ZAMBIAN PHYSICS EDUCATION

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ABSTRACT

Physics education in Zambia has historically emphasized abstract, examination-driven, and largely Eurocentric content, often detached from learners' lived realities. This has contributed to low learner motivation, weak conceptual understanding, and limited application of physics knowledge to real-life contexts, particularly in energy-related topics. In response to these challenges, the Zambian Ministry of Education introduced the Competence-Based Curriculum (CBC) in 2023, emphasizing learner-centred pedagogy, practical application, and the development of holistic competences. This study investigated the effectiveness of Project-Based Learning (PBL), centred on the design and improvement of traditional biomass stoves, as a pedagogical approach for teaching energy concepts in secondary school physics while fostering learner competences and strengthening community engagement. A qualitative case-study design was employed involving 20 Grade 11 physics learners, two physics teachers, three local artisans, and ten community members in Masaiti District, Zambia. Data were collected through learners' reflective journals, focus group discussions, teacher observation records, photo documentation, and community feedback sessions. The findings indicate substantial improvement in learners' conceptual understanding of energy concepts, evidenced by a shift from abstract, formula-based explanations to contextualized reasoning grounded in everyday cooking technologies. The study further revealed significant development of key learner competences, including collaboration, communication, emotional intelligence, and problem-solving. In addition, the improved biomass stoves demonstrated a reduction in charcoal consumption, highlighting positive social, economic, and environmental impacts within the local community. The study concludes that PBL provides an effective and culturally responsive pathway for operationalizing Zambia's CBC in physics education, integrating conceptual mastery, competence development, and community relevance.

KEYWORDS: Project-Based Learning; Physics Education; Competence-Based Curriculum; Biomass Stoves; Decolonising STEM; Community Engagement.

INTRODUCTION

Physics plays a critical role in national development by equipping learners with scientific knowledge and problem-solving skills necessary for technological innovation and sustainable development **(Smith, 2002)**. However, physics education in many African contexts, including Zambia, has been characterized by abstract, content-heavy, and examination-oriented approaches that limit learners' ability to meaningfully apply knowledge in real-world contexts **(Kabombwe & Mulenga, 2019)**. At the senior secondary level, physics syllabi have traditionally emphasized theoretical definitions, mathematical derivations, and standardized examination preparation, often illustrated using examples distant from learners' socio-cultural and economic realities.

In Zambia, topics such as work, energy, thermal physics, and simple machines are frequently taught through idealized industrial or Western technological examples, with limited reference to everyday technologies familiar to learners, such as biomass stoves, borehole water pumps, or locally fabricated tools. This abstract orientation has been associated with persistent challenges in learner motivation, misconceptions in energy-related concepts, and weak transfer of knowledge to practical situations **(Sobuwa & McKenna, 2023)**.

Problem Statement

Despite curriculum intentions to promote relevance and application, physics teaching practices in Zambia have remained insufficiently contextualized, contributing to learners' difficulties in understanding and applying energy concepts **(Kabombwe & Mulenga, 2019)**. The recent introduction of the 2023 Competence-Based Curriculum (CBC) presents an opportunity to address these challenges **(Ministry of Education, 2023)**; however, there is limited empirical evidence on pedagogical strategies that effectively translate CBC principles into classroom practice. There is therefore a need to investigate contextually grounded instructional approaches, such as Project-Based Learning, that integrate conceptual understanding, competence development, and community relevance **(Kolmos, 2021; Chikoko & Muwanga-Zake, 2024)**.

Research Objective

The main objective of this study was to explore how Project-Based Learning can be used as a vehicle for teaching energy concepts in secondary school physics while simultaneously fostering learner competences and strengthening school–community engagement.

Research Questions

1. In what ways does Project-Based Learning influence learners' conceptual understanding of energy in physics?
2. How does PBL foster the development of learner competences such as collaboration, communication, emotional intelligence, and problem-solving?
3. What are the perceived impacts of implementing PBL on the local community through biomass stove projects?

Materials and Methods

This study adopted a qualitative case-study research design to gain an in-depth understanding of the implementation of Project-Based Learning within an authentic classroom and community context. The case-study approach was appropriate as it allowed for rich description and interpretation of learners' experiences, competence development, and community interactions, as recommended in qualitative STEM education research **(Kolmos, 2021)**.

Study Context and Participants

The study was conducted at Chiwala Provincial STEM Secondary School in Masaiti District, Copperbelt Province, Zambia. Participants included 20 Grade 11 physics learners aged between 15 and 17 years, two experienced physics teachers, three local artisans with expertise in biomass stove construction, and ten community members drawn from households using traditional biomass stoves.

Project Implementation Procedure

The PBL intervention was implemented over a four-month period and structured into four phases: needs assessment, design and construction, testing and evaluation, and reflection and dissemination. During the needs assessment phase, learners engaged with community members to identify challenges associated with traditional biomass stoves, including high fuel consumption and smoke emissions. In the design and construction phase, learners worked collaboratively to sketch, plan, and build improved stove prototypes using locally available materials, under the guidance of teachers and artisans.

The testing and evaluation phase involved comparative assessment of traditional and improved stoves in terms of fuel consumption, cooking time, and usability. Community members participated by testing the stoves in household settings and providing feedback. The final reflection and dissemination phase enabled learners to document their learning through reflective journals and present their findings to community stakeholders.

Data Collection Methods

Multiple qualitative data collection methods were employed to ensure triangulation and credibility of findings. Learners maintained weekly reflective journals documenting conceptual learning and competence development. Focus group discussions were conducted with learners and community members to capture perceptions of learning relevance and community impact. Teachers maintained structured observation records aligned with CBC competence domains. Photo documentation provided visual evidence of learner engagement and collaborative practices.

Data Analysis

Data were analysed using thematic analysis. Transcripts and written records were coded inductively and grouped into themes related to conceptual understanding of energy, learner competence development, and community impact. Triangulation across data sources enhanced trustworthiness and analytic rigor.

Ethical Considerations

Participation was voluntary, and informed consent was obtained from all participants.

RESULTS AND DISCUSSION

Conceptual Understanding of Energy

The findings revealed notable improvements in learners' conceptual understanding of energy. Prior to the PBL intervention, learners frequently described energy using abstract definitions and mathematical formulas without contextual reference, a challenge widely reported in physics education literature **(Kabombwe & Mulenga, 2019)**. Following the intervention, learners demonstrated the ability to explain energy efficiency, heat transfer, and combustion processes in relation to biomass stove performance, indicating deeper conceptual understanding.

This progression reflects the movement from abstract to contextualized knowledge described in semantic wave theory **(Sobuwa & McKenna, 2023)** and supports evidence that Project-Based Learning enhances conceptual understanding through real-world application **(Kolmos, 2021)**.

Table 1 presents comparative evidence of learners' responses before and after the Project-Based Learning intervention, illustrating clear improvements in conceptual understanding of energy through contextualized explanations.

Table 1. Evidence of Learners' Conceptual Understanding of Energy Before and After PBL.

Indicator of Conceptual Understanding	Pre-PBL Learner Responses (Baseline Evidence)	Post-PBL Learner Responses (After Biomass Stove Project)	Interpretation (Conceptual Shift)
Understanding of energy definition	"Energy is the ability to do work."	"Energy is the ability to do work, but in our stove it shows how heat is transferred from the burning charcoal to the pot."	Shift from abstract definition to applied understanding
Explanation of heat transfer	"Heat moves by conduction, convection and radiation."	"Heat from the charcoal is transferred by conduction through the metal stove and by convection of hot air inside the stove."	Improved contextual application of heat transfer modes
Energy efficiency	"Efficiency is output divided by input."	"The improved stove is more efficient because less heat is lost to the air and more heat is concentrated	Transition from formula-based to functional reasoning

		under the pot."	
Relationship between fuel and energy	"Charcoal gives energy."	"Using less charcoal still cooks food faster because the stove reduces heat loss and improves combustion."	Deeper understanding of energy use and conservation
Distinction between heat and temperature	"Heat and temperature are the same."	"Temperature shows how hot the stove is, but heat is the energy transferred to the pot during cooking."	Correction of common misconception
Real-life application of energy concepts	"Energy is used in machines like engines."	"Energy concepts explain why our improved biomass stove saves fuel and cooks faster at home."	Strong transfer of knowledge to everyday context

Learner Competence Development

The PBL approach also facilitated the development of learner competences emphasized in the CBC. Learners demonstrated collaboration, communication, emotional intelligence, and problem-solving through authentic design and construction tasks. These outcomes align with international findings that PBL supports holistic competence development beyond content mastery **(Kolmos, 2021)** and with place-based learning frameworks that emphasize meaningful, socially embedded learning **(Smith, 2002)**.

Table 2 summarizes qualitative evidence demonstrating how Project-Based Learning fostered the development of key learner competences aligned with Zambia's Competence-Based Curriculum.

Table 2. Evidence of Learner Competence Development Through Project-Based Learning.

Targeted Competence (CBC)	**Evidence from Learner Journals & Observations**	**Observed Behavior During PBL Activities**	**Interpretation of Competence Development**
Collaboration	"At first we argued about the design, but later we shared roles and worked together to	Learners divided tasks (designing, molding, testing) and supported one another during	Improved teamwork, role-sharing, and collective

	finish the stove."	construction.	responsibility
Communication	"I was able to explain to community members why the stove saves charcoal using physics ideas."	Learners confidently presented stove designs and explained energy concepts to peers and community members.	Enhanced verbal communication and scientific explanation skills
Emotional Intelligence	"When my design failed, I felt discouraged, but my friends encouraged me and we tried again."	Learners managed frustration, resolved conflicts peacefully, and showed patience during group work.	Growth in self-regulation, empathy, and resilience
Problem-solving	"We changed the shape of the stove opening to reduce smoke and save heat."	Learners engaged in trial-and-error design improvements without relying solely on teacher instruction.	Development of independent reasoning and innovative thinking


Figure 1: Learners collaborating and communicating during designing and construction of the biomass stove, Figure 2 provides visual evidence of learner collaboration and communication during group-based stove construction activities.

Community Impact and Decolonizing STEM

Community engagement emerged as a significant outcome of the project. The collaboration between learners and artisans validated indigenous knowledge and strengthened school–community relationships, supporting calls for decolonized STEM education that integrates local epistemologies with formal science **(Chikoko & Muwanga-Zake, 2024)**.

Table 3 presents evidence of the social, economic, and educational impacts of the Project-Based Learning intervention on the local community.

Table 3. Evidence of Community Impact Resulting from the Biomass Stove Project.

Aspect of Community Impact	Community Member / Artisan Feedback	Observed Outcome	Interpretation of Impact
Fuel efficiency	"This stove uses less charcoal than our usual mbaula."	Reduced charcoal consumption during cooking trials.	Improved household energy efficiency
Economic benefit	"I will spend less money on charcoal when using the improved stove."	Decreased fuel expenditure for participating households.	Positive economic impact for families
Cultural relevance	"The stove still works like the ones we know, but it is better."	Acceptance of improved stove designs without cultural resistance.	Successful integration of indigenous knowledge
School–community relationship	"We did not know learners could help solve real problems at home."	Increased community trust and engagement with the school.	Strengthened school–community partnership
Knowledge transfer	"Now I understand why filling clay in the stove saves heat."	Community members gained basic understanding of energy efficiency concepts.	Informal science learning beyond the classroom

Community participation in stove designing and construction sessions is illustrated in Figure 2, highlighting the integration of indigenous knowledge and school–community collaboration.

Figure 2: learners interacting with local artisans.

Limitations of the Study

The study was limited to a single school and a relatively short implementation period, restricting the generalizability of findings and long-term assessment of stove adoption. Additionally, the qualitative nature of competence assessment presents challenges for objective measurement and comparability across contexts.

CONCLUSION

This study concludes that Project-Based Learning offers an effective and culturally responsive pedagogical approach for implementing Zambia's Competence-Based Curriculum in physics education **(Ministry of Education, 2023)**. By situating energy concepts within the familiar context of biomass stoves, learners achieved deeper conceptual understanding, developed essential competences, and contributed meaningfully to their community. The findings underscore the potential of PBL to bridge the gap between curriculum policy and classroom practice while advancing decolonized STEM education **(Chikoko & Muwanga-Zake, 2024)**.

REFERENCES

1. Chikoko, V., & Muwanga-Zake, J. (2024). Decolonising STEM education: Integrating indigenous knowledge systems in curriculum and pedagogy. Frontiers in Education, 9, Article 1480199. https://doi.org/10.3389/feduc.2024.1480199
2. Kabombwe, Y. M., & Mulenga, I. M. (2019). Curriculum at the crossroads: Implementation of the secondary school curriculum in Zambia. University of Zambia Press.
3. Kolmos, A. (2021). Problem-based and project-based learning in engineering education. Routledge.

4. Ministry of Education. (2023). Zambia education curriculum framework. Curriculum Development Centre.
5. Smith, G. A. (2002). Place-based education: Learning to be where we are. Phi Delta Kappan, 83(8), 584–594. https://doi.org/10.1177/003172170208300806
6. Sobuwa, S., & McKenna, S. (2023). Semantic waves in project-based learning: Connecting abstract science knowledge to everyday contexts. Education Sciences, 13(1), 2. https://doi.org/10.3390/educsci13010002