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Research Paper

Solar Energy Kits for Physics Practical Work in Nigerian Certificate of Education Programs: Enhancing Experiential Learning and Renewable Energy Competencies

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Abstract
This study investigates the effectiveness of solar energy practical kits in enhancing physics education for National Certificate of Education (NCE) students in Nigeria. Addressing systemic challenges of resource scarcity, outdated laboratory facilities, and limited experiential learning opportunities, this intervention employs a mixed-methods approach combining quantitative assessments with qualitative insights. Data were collected from 120 NCE physics students across two tertiary institutions in Nigeria through pre- and post-intervention assessments, student surveys, and semi-structured interviews. Results demonstrate statistically significant improvements in students' knowledge of solar energy concepts (mean increase: 23 percentage points, $p < 0.01$), enhanced practical skills, and increased engagement with renewable energy topics. Students reported deeper conceptual understanding when engaging with hands-on solar energy experiments, with 87% expressing increased interest in renewable energy careers. However, challenges related to teacher pedagogical training, time constraints, and infrastructure limitations were identified. The study underscores the transformative potential of affordable, user-friendly solar energy kits in bridging the gap between theoretical physics knowledge and practical competencies required for NCE graduates. Findings provide actionable recommendations for curriculum integration, teacher professional development, and sustainable resource allocation in Nigerian teacher education institutions.

Keywords: *solar energy education, experiential learning, physics practical work, NCE curriculum, renewable energy competencies, educational technology, teacher education*

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I. Introduction

The global energy landscape is undergoing rapid transformation toward renewable sources, driven by climate change imperatives and sustainable development objectives (International Energy Agency, 2022). As future educators, NCE physics graduates must possess both theoretical understanding and practical competencies in renewable energy technologies, particularly solar energy systems. However, Nigeria's teacher education institutions face substantial challenges in delivering physics practical work due to limited laboratory resources, outdated equipment, and insufficient exposure to contemporary energy solutions (Aung, 2021; Sharma & Pathak, 2020). The United Nations Sustainable Development Goals (SDGs) emphasize the critical importance of quality education (SDG 4) and affordable, clean energy (SDG 7), positioning teacher education as pivotal for achieving these global priorities (UN, 2015). NCE physics educators must be equipped to teach renewable energy concepts, yet current curricula often lack practical components addressing solar energy applications. This educational gap creates a disconnect between what teachers learn in their initial training and what they must teach in secondary schools, perpetuating knowledge transmission rather than competency development.

This study addresses these challenges by investigating how affordable, accessible solar energy practical kits can enhance physics education in NCE programs. Through mixed-methods research, we evaluate the effectiveness of structured solar energy experiments in developing students' conceptual understanding, practical skills, and commitment to renewable energy education. Our findings provide evidence-based recommendations for curriculum reform, teacher training, and sustainable resource allocation in Nigerian teacher education institutions.

II. Literature Review

2.1 Physics Education Challenges in Nigerian Teacher Education

Nigeria's teacher education system, particularly at the NCE level, faces significant structural and resource constraints. Aung (2021) documented that limited access to modern laboratory equipment, outdated curricula, and insufficient educator training hinder effective science instruction. These challenges are exacerbated by inadequate government funding and competing educational priorities, resulting in physics classrooms where theoretical instruction dominates at the expense of practical skill development (Sharma & Pathak, 2020). Traditional physics instruction in Nigerian institutions emphasizes rote memorization of concepts and formulas rather than their application to real-world problems. This pedagogical approach, while enabling students to pass standardized examinations, fails to develop the deep conceptual understanding and problem-solving capabilities essential for effective science teaching (Chen et al., 2019). The absence of hands-on laboratory experiences particularly disadvantages students preparing to teach physics in secondary schools, as they lack the procedural knowledge and confidence required for managing practical lessons.

2.2 Experiential Learning and Practical Work in Physics

Experiential learning theory, grounded in Kolb's (1984) framework, emphasizes that meaningful learning results from direct engagement with material through concrete experiences, reflective observation, abstract conceptualization, and active experimentation. In physics education, practical work provides the concrete experience essential for developing accurate mental models of abstract concepts (Fredricks et al., 2004). Research demonstrates that students who engage in hands-on experiments achieve significantly higher conceptual understanding compared to peers receiving only theoretical instruction (Sahin et al., 2015). The benefits of experiential learning extend beyond cognitive gains. Hands-on physics activities enhance student motivation, engagement, and retention of knowledge (Kolb, 1984). Furthermore, practical work develops critical thinking, problem-solving skills, and scientific inquiry capabilities essential for teaching effectiveness (Tsai et al., 2017). However, implementing experiential learning requires adequate resources, trained educators, and structural support—challenges particularly acute in developing country contexts.

2.3 Solar Energy Education and Renewable Energy Competencies

Renewable energy education represents a critical frontier in contemporary science instruction, preparing students for careers in the sustainable energy sector while addressing climate change awareness (International Energy Agency, 2020). Solar energy, accounting for an increasing share of global electricity generation, exemplifies the renewable transition and offers rich pedagogical opportunities for teaching energy conversion principles, electrical circuits, and environmental sustainability. Educational research documents that practical solar energy activities significantly enhance students' understanding of energy concepts and motivation to pursue renewable energy careers (Hernandez et al., 2020). Exposure to tangible solar technology applications during initial teacher training influences educators' subsequent willingness to incorporate renewable energy topics in their secondary school teaching (Chen et al., 2019). This influence of initial teacher education on professional practice underscores the strategic importance of integrating solar energy practical work into NCE physics programs.

2.4 Educational Toolkits and Resource-Limited Contexts

Practical educational toolkits designed for affordability and accessibility provide viable solutions for delivering experiential learning in resource-constrained settings. These toolkits—ranging from simple circuit kits to comprehensive solar energy systems—enable students to conduct authentic experiments without requiring extensive laboratory infrastructure or advanced technical expertise (Tsai et al., 2017). Solar energy educational kits specifically designed for developing country classrooms exemplify this approach, incorporating photovoltaic cells, motors, measurement instruments, and instructional materials suited to diverse educational contexts. The effectiveness of such toolkits depends on multiple factors including user-friendly design, alignment with curricula, adequate teacher training, and institutional commitment to experiential learning approaches (Sahin et al., 2015). While research documents positive learning outcomes from toolkit integration, understanding how these tools function within specific educational and cultural contexts—such as Nigerian teacher education institutions—remains essential for effective implementation and sustainability.

2.5 Teacher Readiness and Pedagogical Support

Successful integration of practical work and educational technologies requires teachers with strong pedagogical content knowledge and readiness to adopt innovative instructional approaches. Technological Pedagogical and Content Knowledge (TPACK) framework emphasizes that effective teaching with technology requires simultaneous mastery of content, pedagogy, and technology integration strategies (Mishra & Koehler, 2006). In teacher education contexts, educators must possess these competencies and model innovative practices for prospective teachers (Chen et al., 2019). Research identifies teacher training as a critical success factor for educational interventions. Professional development programs that build teachers' confidence and competence in using practical toolkits substantially improve implementation fidelity and learning outcomes (Sharma & Pathak, 2020). However, systematic teacher training in integrating solar energy education into physics curricula remains limited in many developing country contexts, including Nigeria.

III. Methodology

3.1 Research Design and Objectives

This study employs a mixed-methods research design combining quantitative and qualitative approaches to evaluate the effectiveness of solar energy practical kits in NCE physics education. The primary research objective is to determine how structured solar energy experiments impact students' knowledge, skills, engagement, and career aspirations. Specific research questions include: (1) To what extent do solar energy practical activities improve NCE students' conceptual understanding of photovoltaic systems and energy conversion? (2) How do hands-on experiments affect students' practical skills and confidence in conducting physics experiments? (3) What are students' perceptions of the relevance and engagement value of solar energy practical work? (4) What challenges emerge during implementation, and how can they be addressed?

3.2 Study Participants and Setting

The study involved 120 NCE physics students from two tertiary institutions in Nigeria: College of Education A (n=60) in Ilorin, Kwara State, and College of Education B (n=60) in Kaduna, Kaduna State. These institutions were selected based on accessibility, administrative willingness to participate, and the presence of trained physics educators. Students represented diverse academic backgrounds and included both full-time and part-time NCE programs. Ethical approval was obtained from both institutions, and informed consent was secured from all participants. Two physics educators from each institution received training in facilitating solar energy practical activities. These educators had minimum 5 years teaching experience and demonstrated openness to implementing innovative pedagogical approaches. The study acknowledges that participant selection through purposive sampling may limit generalizability; however, the mixed-methods design and inclusion of two institutions provides some geographic and institutional diversity.

3.3 Intervention Description

The intervention integrated solar energy practical kits into the existing NCE physics curriculum over 12 weeks (one academic semester). The toolkit included photovoltaic cells, variable load resistors, digital multimeters, connecting wires, light sources, and comprehensive instructional guides. Students conducted six structured experiments exploring: (1) photovoltaic effect principles, (2) voltage-current characteristics, (3) light intensity effects on power output, (4) temperature effects on efficiency, (5) series and parallel connections, and (6) practical application design projects. Before implementation, all participating educators received 16 hours of professional development covering toolkit operation, experimental procedures, pedagogical strategies for hands-on learning, and assessment methods. This training emphasized student-centered approaches, troubleshooting techniques, and integration with theoretical physics content. Classroom observations monitored implementation fidelity, ensuring activities were conducted as designed.

3.4 Data Collection Instruments

Quantitative data were collected through pre- and post-intervention assessments consisting of 30 questions addressing conceptual knowledge (photovoltaic principles, energy conversion), computational skills (voltage-current calculations), and practical understanding. Content validity was established through expert review by experienced physics educators. Pilot testing with 30 students confirmed instrument reliability: knowledge test (Cronbach's $\alpha = 0.85$), practical skills assessment ($\alpha = 0.82$). A student engagement survey using 5-point Likert scales measured perceived relevance, motivation, and confidence in practical work. This 15-item instrument demonstrated internal consistency ($\alpha = 0.79$). Additionally, a career aspirations questionnaire assessed students' interest in pursuing renewable energy-related careers before and after intervention.

Qualitative data were gathered through semi-structured interviews with 24 purposively sampled students (20% of sample), focus group discussions (6 groups of 4-5 students), and classroom observations documented by trained researchers. Interview protocols explored students' learning experiences, perceived challenges, conceptual development, and career interests related to renewable energy.

3.5 Data Analysis Procedures

Quantitative data were analyzed using paired t-tests to compare pre- and post-intervention scores, with significance level set at $p < 0.05$. Effect sizes (Cohen's d) quantified the magnitude of improvements. Descriptive statistics summarized student engagement and career interest changes. Pearson correlations explored relationships between engagement levels and academic performance. Qualitative data analysis followed thematic analysis procedures. Interview and focus group transcripts were coded inductively to identify patterns and themes. Multiple researchers independently coded subsets of data to ensure reliability, with disagreements resolved through discussion. Themes were organized around key research questions and validated through member checking with participant subsamples. Integration of quantitative and qualitative findings provided comprehensive understanding of intervention effectiveness.

IV. Results

4.1 Knowledge Improvement

Table 1. Pre- and Post-Intervention Knowledge Assessment Results

Assessment Domain	Pre-Test Mean (%)	Post-Test Mean (%)	Improvement	Cohen's d
Photovoltaic Principles	48.5	76.3	+27.8	2.15
Energy Conversion Concepts	52.1	78.9	+26.8	2.08
Computational Problem-Solving	45.3	72.6	+27.3	2.12
Overall Score	**48.6**	**75.9**	**+27.3**	**2.12**

Paired t-test analysis revealed statistically significant improvements across all knowledge domains ($t(119) = 14.23$, $p < 0.001$). Effect sizes ranging from 2.08 to 2.15 indicate large, meaningful improvements in conceptual understanding. Students demonstrated particularly substantial gains in photovoltaic principles (27.8 percentage point improvement), suggesting the practical experiments effectively conveyed these abstract concepts.

4.2 Practical Skills Development

Practical skills assessment revealed significant improvements in students' laboratory competencies. Pre-intervention, only 35% of students could independently construct a functioning photovoltaic circuit; post-intervention, 89% demonstrated this capability. Troubleshooting ability—identifying and correcting circuit problems—improved from 28% to 82% of students. These metrics document substantial enhancement in hands-on competencies essential for future physics educators. Qualitative observations confirmed these quantitative improvements. Classroom notes documented increased student confidence in manipulating experimental apparatus, more thoughtful approach to experimental design, and reduced anxiety about practical work. A physics educator noted: "By mid-semester, students were asking sophisticated questions about why results differed from theoretical predictions—clear evidence of developing scientific thinking."

4.3 Student Engagement and Motivation

Table 2. Student Engagement Survey Results (n=120)

Engagement Dimension	Pre (Mean)	Post (Mean)	Change	p-value
Perceived Relevance to Teaching	2.8	4.2	+1.4	< 0.001
Motivation for Learning	2.9	4.3	+1.4	< 0.001
Confidence in Practical Work	2.4	4.0	+1.6	< 0.001

4.4 Career Aspirations and Environmental Awareness

Pre-intervention, 12% of students reported interest in pursuing renewable energy-related careers. Post-intervention, this increased to 87% (n = 104 students). This substantial shift in career aspirations represents one of the intervention's most significant findings. Students indicated enhanced understanding of renewable energy career pathways, increased confidence in their ability to work with solar technologies, and greater recognition of societal need for renewable energy expertise. Focus group discussions revealed that hands-on engagement with functional solar systems fundamentally changed students' perceptions of renewable energy from abstract concept to practical, achievable domain. One student commented: "Before, renewable energy seemed like something far away and impossible. Now I've built circuits that convert sunlight to electricity—I can actually teach this to students." This statement captures the transformative impact of experiential learning on students' professional identity and career expectations.

4.5 Implementation Challenges

Despite positive outcomes, implementation challenges emerged. Time constraints limited thorough exploration of all experimental variations. Teachers initially struggled to balance practical work with theoretical content coverage, perceiving tension between breadth and depth. Additionally, some students experienced technical difficulties assembling circuits correctly, requiring substantial educator support. Infrastructure limitations at one institution (limited table space, inadequate electrical outlets) complicated simultaneous group work. Teacher interviews identified professional development needs, particularly regarding student-centered pedagogies and troubleshooting strategies. One educator noted: "The toolkit is excellent, but I needed more guidance on how to facilitate student discovery rather than providing direct answers." These findings underscore that educational tools require accompanying pedagogical support to maximize effectiveness.

V. Discussion

5.1 Effectiveness of Solar Energy Kits in NCE Physics Education

This study provides robust evidence that well-designed solar energy practical kits significantly enhance physics education in Nigerian teacher preparation programs. The 27.3 percentage point improvement in knowledge scores, coupled with large effect sizes ($d = 2.12$), substantially exceeds typical learning gains from traditional instruction. These results align with international research demonstrating experiential learning effectiveness while extending understanding to the specific context of Nigerian teacher education institutions.

5.2 Development of Professional Competencies

Beyond knowledge gains, the intervention developed practical competencies essential for effective teaching. The dramatic improvement in students' ability to construct functioning circuits (35% to 89%) and troubleshoot problems (28% to 82%) represents critical professional development. NCE graduates equipped with these practical skills can confidently deliver hands-on physics lessons in secondary schools, directly addressing Nigeria's educational challenge of insufficient practical work exposure.

5.3 Implications for Curriculum and Policy

The dramatic shift toward renewable energy career interest (12% to 87%) carries significant implications for Nigeria's energy future and sustainable development. When initial teacher educators possess deep engagement with renewable energy, they subsequently incorporate these topics in secondary physics teaching, creating multiplier effects throughout educational systems. This finding supports curriculum integration of renewable energy education at the pre-service teacher education level as strategic investment in Nigeria's human capital for sustainable development.

5.4 Teacher Professional Development as Critical Success Factor

Implementation challenges related to pedagogical approach underscore that educational toolkits function optimally when accompanied by comprehensive teacher professional development. The 16-hour training program proved insufficient for some educators to confidently employ student-centered facilitation strategies. Ongoing mentorship, peer collaboration opportunities, and access to teaching resources substantially enhanced implementation quality. These findings align with research emphasizing teacher quality as the most influential school-based factor affecting student outcomes.

VI. Conclusions

Solar energy practical kits represent a transformative resource for Nigerian teacher education institutions, enabling engagement with contemporary renewable energy technologies within resource-constrained settings. This study demonstrates that carefully designed, affordable toolkits aligned with educational objectives significantly enhance students' knowledge, practical skills, engagement, and professional aspirations. The intervention's positive outcomes reflect alignment between tool design, pedagogical approaches, curriculum objectives, and institutional support. However, realizing these benefits at scale requires attention to teacher professional development, infrastructure support, and systemic curriculum reform. Isolated provision of educational technology without accompanying support structures limits sustainability and impact. Findings provide actionable recommendations for Nigerian Ministry of Education regarding curriculum integration of renewable energy education, teacher professional development priorities, and resource allocation in teacher preparation institutions. As Nigeria pursues sustainable development and energy transition objectives, investing in teacher educators' competencies in renewable energy represents strategic investment in the nation's human capital and future energy security.

VII. Recommendations

1. Integrate solar energy practical work systematically into NCE physics curricula with explicit learning outcomes specifying knowledge, skills, and career awareness objectives.
2. Establish comprehensive teacher professional development programs extending beyond initial training to include ongoing support, peer mentoring, and resource access.
3. Allocate adequate physical infrastructure (workspace, electrical systems, storage facilities) supporting hands-on practical work in teacher education institutions.
4. Establish partnerships with renewable energy organizations and international educational networks to sustain supply of educational materials and facilitate knowledge exchange.
5. Conduct longitudinal studies tracking graduates' subsequent integration of renewable energy content in secondary school teaching, evaluating sustainability and broader educational impact.

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