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Low-Cost ICT Instructional Package for Teaching Electricity Concepts in Physics

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ABSTRACT

Electricity is one of the most abstract and misconception-prone topics in secondary school physics. Students cannot see current, potential difference or energy transfer in a circuit, and many hold persistent misconceptions, such as believing that current is used up by a bulb or that a battery supplies a fixed current. In Nigerian secondary schools, these difficulties are compounded by poorly equipped laboratories, large classes and limited access to expensive educational technology. This paper reports the design and development of a low-cost ICT instructional package for teaching electricity concepts in senior secondary physics. Guided by the ADDIE instructional design model and grounded in constructivist learning theory, Mayer's cognitive theory of multimedia learning and the TPACK framework, the package combines free offline interactive simulations, smartphone-based measurement applications, short teacher-made video demonstrations, a basic projector or shared screen, low-cost physical circuit kits and messaging-application support. It is organised into six lesson units covering electric charge and current, potential difference and electromotive force, Ohm's law and resistance, series and parallel circuits, electrical energy and power, and household electricity and safety. Each unit follows a predict-observe-explain (POE) sequence that targets documented misconceptions. The package is designed to run on equipment many schools or teachers already own, to function without continuous internet access, and to complement rather than replace hands-on practical work. The paper outlines implementation guidelines and a plan for evaluating the package's effect on students' conceptual understanding, and recommends teacher training and wider trials.

Keywords: *ICT instructional package, electricity concepts, physics education, simulations, misconceptions, low-cost technology*

Introduction Physics underpins engineering, medicine, energy and information technology, and electricity is among its most important topics. Every modern device depends on electrical principles, and the senior secondary physics curriculum in Nigeria devotes substantial attention to current electricity, circuits, electrical energy and power. A solid grasp of electricity is essential for students who will pursue science, engineering and technical careers, and useful for every citizen who handles electrical appliances.

Yet electricity is notoriously difficult to learn. Its central quantities, charge, current, potential difference and resistance, are invisible and must be inferred from their effects. Research over several decades has documented robust misconceptions among students at all levels. Students often believe that current is "used up" as it passes through a bulb, that a battery always delivers the same current regardless of the circuit, that only the components before a bulb affect its brightness, or that potential difference and current are the same thing (McDermott & Shaffer, 1992; Shipstone, 1984). Engelhardt and Beichner (2004) found such misconceptions persisting even among university students after instruction. Conventional teaching, which emphasises formula manipulation such as V = IR, often leaves these misconceptions untouched (Banda & Nzabahimana, 2021; Jita et al., 2026).

In Nigeria, additional obstacles exist. Many public secondary school laboratories lack functioning ammeters, voltmeters, rheostats and circuit components. Classes are large, practical periods are short, and some physics teachers have limited access to professional development. Commercial educational technology packages are expensive and often require reliable electricity and internet connectivity, which many schools lack. At the same time, smartphones are now widespread among teachers, free and offline-capable physics simulations are available, and low- cost projectors and solar power options are increasingly affordable.

These conditions create an opportunity to design instructional packages that harness inexpensive ICT to make electricity concepts visible and interactive, although successful integration also depends on teacher preparation, facilitating conditions and context-sensitive implementation (Srinivasan et al., 2024; UNESCO, 2023).

Statement of the Problem Students' poor performance and persistent misconceptions in electricity concepts suggest that the way electricity is taught in many Nigerian secondary schools is inadequate. Laboratories are poorly equipped, and expensive ICT solutions are beyond the reach of most public schools.

There is a need for an instructional package that uses readily available, low-cost ICT resources to help teachers make electricity concepts concrete, address misconceptions and engage students actively, while remaining practical in schools with limited power and connectivity.

Purpose of the Paper The purpose of this paper is to present the design and development of a low-cost ICT instructional package for teaching electricity concepts in senior secondary physics.

Specifically, the paper:

1. reviews the literature on students' difficulties with electricity and on ICT in physics teaching;

2. describes the theoretical basis of the package;

3. outlines the procedure followed in designing and developing the package;

4. describes the components and lesson units of the package; and

5. provides implementation guidelines and a plan for evaluating its effectiveness.

Review of Related Literature Students' Difficulties with Electricity Shipstone (1984) identified several mental models students use to reason about simple circuits, including the unipolar model (current flows from one terminal only), the attenuation model (current decreases as it passes through components) and the sharing model (current is shared equally among components). McDermott and Shaffer (1992) showed that many students lack a coherent conceptual model of a circuit and cannot apply formulas meaningfully. They found that instruction emphasising hands-on observation and reasoning, rather than formula use, was more effective in overcoming misconceptions. Engelhardt and Beichner (2004) developed a diagnostic test of direct-current circuit concepts and confirmed that misconceptions about current, potential difference and resistance are widespread and resistant to conventional teaching. Engelhardt and Beichner's findings remain relevant, and later evidence continues to support explicit attention to students' reasoning about electricity; a 2026 systematic review of secondary-level electricity and magnetism research synthesises empirical work from 2019, 2024 and highlights conceptual-change approaches, inquiry and simulations as important instructional considerations (Jita et al., 2026).

ICT and Simulations in Physics Teaching Interactive simulations allow students to manipulate variables and observe effects that are otherwise invisible. The PhET Interactive Simulations project at the University of Colorado Boulder offers free simulations, including a widely used circuit construction kit that animates moving charges, allowing students to see that current is the same at all points in a series loop.

Wieman et al. (2008) argued that well-designed simulations engage students in exploration much as scientists explore. Finkelstein et al. (2005) found that students who learned about circuits with a simulation in place of physical equipment performed better on conceptual questions and on building real circuits than students who used physical equipment. A review by Rutten et al. (2012) concluded that computer simulations generally enhance traditional instruction, especially when integrated with teacher guidance and inquiry tasks. More recent reviews similarly report that PhET simulations can improve conceptual understanding when embedded in active-learning and inquiry-oriented instruction (Banda & Nzabahimana, 2021;

Medeiros Jr. et al., 2024; Ramaila, 2024; Manligoy et al. 2025).

Low-Cost and Mobile Technology in Science Education Smartphones contain sensors and computing power that can turn them into measuring instruments. The phyphox application, developed at RWTH Aachen University, gives free access to a phone's sensors for physics experiments (Staacks et al., 2018). Many PhET simulations run

offline in a web browser or on Android devices. Combined with low-cost projectors, solar power banks and inexpensive component kits, such tools allow schools with limited budgets to offer interactive, inquiry-based physics instruction, provided that device access, teacher support, maintenance and local learning needs are considered (Srinivasan et al., 2024; UNESCO, 2023).

Theoretical Framework Constructivism. Constructivist theory holds that learners build new knowledge on the basis of existing understanding. Misconceptions are not empty spaces but alternative models that must be challenged. The package uses a predict-observe-explain (POE) sequence: students first predict what will happen, then observe the outcome in a simulation or real circuit, and then explain discrepancies. This sequence creates cognitive conflict, which is a recognised route to conceptual change and is consistent with recent evidence supporting guided, simulationenhanced active learning in physics (Banda & Nzabahimana, 2021; Jita et al., 2026).

Cognitive Theory of Multimedia Learning. Mayer (2009) proposed that people learn more deeply from words and pictures together than from words alone, provided that instruction respects the limited capacity of working memory. Principles such as signalling key information, avoiding extraneous material and segmenting content into manageable parts guided the design of the package's videos and slides.

TPACK. The Technological Pedagogical Content Knowledge framework (Mishra & Koehler, 2006) emphasises that effective technology integration arises from the interplay of content, pedagogy and technology. The package is designed so that each ICT tool is tied to a specific electricity concept and a specific teaching strategy, rather than used for its own sake, consistent with guidance that educational technology should be appropriate, equitable, evidence-informed and sustainable (UNESCO, 2023).

Design and Development Procedure The package was developed using the ADDIE instructional design model, which comprises five phases: Analysis, Design, Development, Implementation and Evaluation (Branch, 2009).

DESIGN AND DEVELOPMENT PROCEDURE

1. The package was developed using the ADDIE instructional design model, which comprises five phases: Analysis, Design, Development, Implementation and Evaluation (Branch, 2009).

2. Analysis. The senior secondary physics curriculum was reviewed to identify the electricity topics to be covered. Research on misconceptions was reviewed to identify the conceptual difficulties to target. The context of typical Nigerian public secondary schools was analysed: availability of electricity, internet, devices and laboratory equipment; class sizes; and teachers' ICT competence. The key constraints identified were limited and unreliable power, little or no internet, few computers, and large classes, alongside widespread teacher ownership of smartphones.

3. Design. Learning objectives were written for each unit. Low-cost ICT tools were selected against criteria of cost (free or inexpensive), offline functionality, compatibility with smartphones or a single laptop, relevance to specific concepts, and ease of use. Each unit was structured around the predict-observe-explain sequence and linked to specific misconceptions.

4. Development. Lesson plans, student worksheets, POE prompts, short video demonstrations (recorded on a smartphone), slide presentations and offline simulation files were produced. A teacher's guide was written explaining setup, troubleshooting and pedagogy. Materials were reviewed by experts in physics education and educational technology for accuracy and suitability, and revised accordingly.

5. Implementation. The package is intended to be delivered by physics teachers in regular class periods, as described in the implementation guide below.

6. Evaluation. Formative evaluation was carried out through expert review during development. Summative evaluation of the package's effect on students' conceptual understanding is planned, as outlined in the evaluation plan below.

Description of the Package Components Table 1. Components of the low-cost ICT instructional package Component Description Purpose Offline interactive simulations PhET circuit construction kit Make current flow and the and related simulations, effects of changing downloaded to a laptop or components visible; allow safe Android phone for offline use experimentation Smartphone measurement Free sensor apps such as Turn phones into dataapps phyphox, used where suitable collection tools; connect for measurements and data physics to familiar devices recording Teacher-made video Short (2, 4 minute) Show real phenomena where demonstrations smartphone videos of real equipment is scarce; allow circuit experiments and replay for revision household electrical safety Slide presentations Simple slides with diagrams, Structure lessons and focus POE questions and key ideas, attention on key concepts following multimedia design principles Display device A low-cost projector, a TV via Share simulations and videos cable, or a laptop screen for with the whole class from one small groups device Power backup A solar power bank or small Keep devices running during solar kit power outages Low-cost physical circuit kits Torch bulbs, holders, dry cells, Ensure hands-on practice connecting wires, switches, complements virtual work resistors and a basic multimeter per group Messaging-application group A class group on a common Share videos, worksheets and messaging app revision questions with students outside class Teacher's guide and Printed lesson plans, POE Support consistent use by worksheets worksheets and assessment teachers with varying ICT items experience Lesson Units Table 2. Lesson units, ICT activities and targeted misconceptions Unit Concepts Core ICT and Misconceptions practical activities targeted

1. Electric charge and Charge, current as Simulation showing Current flows from current flow of charge, unit of moving charges in a one terminal only;

current, simple circuit; video current is used up by a conventional current of a bulb lighting bulb and electron flow when the circuit is closed

2. Potential Potential difference, Simulation Battery is a source of difference and e.m.f. electromotive force, comparing cells of constant current;

the role of the cell different voltage; voltage and current measuring cell are the same thing voltage with a multimeter

3. Ohm's law and Relationship between Simulation varying Resistance only resistance V and I, resistance, voltage and resistance affects the component factors affecting and recording after it; V = IR as a resistance current; graphing V formula without against I on a phone or meaning by hand; real resistor kit

4. Series and parallel Current and voltage in POE tasks predicting Current is shared circuits series and parallel, bulb brightness in equally; adding bulbs equivalent resistance series and parallel; in parallel always building circuits in makes all bulbs simulation and with dimmer; order of physical kits components matters in series

5. Electrical energy Energy transfer, Simulation showing Energy and power are and power power, the kilowatt-energy transfer; the same; electricity hour, cost of calculating household is "consumed" rather electricity energy use and cost than energy from appliance transferred ratings

6. Household Wiring, fuses, circuit Video demonstrations Thicker or bypassed electricity and safety breakers, earthing, of safe wiring and fuses are harmless;

safety practices fuse operation; case earthing is discussion of unnecessary common hazards in Nigerian homes Lesson Structure Each unit follows a five-step sequence designed for a typical 80-minute double period:

1. Engage (10 minutes): A short video or real-life question about electricity in daily life.

2. Predict (10 minutes): Students individually write predictions about a circuit situation, then compare with a partner.

3. Observe (25 minutes): The teacher runs the simulation for the class, or groups use phones or physical kits, to test predictions.

4. Explain (20 minutes): Students explain the results, the teacher addresses misconceptions explicitly, and key ideas are summarised on slides.

5. Apply and assess (15 minutes): Students solve conceptual and quantitative problems; revision materials are shared through the class messaging group.

IMPLEMENTATION GUIDELINES

1. Prepare offline. Download all simulations, videos and slides to the teacher's laptop or phone in advance, so that lessons do not depend on internet access.

2. Plan for power. Charge devices and the solar power bank before class, and keep printed worksheets as a fallback if devices fail.

3. Use one device for many. Where only one device is available, project or display the simulation for the whole class and ask groups to call out predictions and instructions, so that every student participates in the POE cycle.

4. Combine virtual and real. Follow each simulation activity with a physical circuit task using the low-cost kits. Simulations build the model; physical circuits confirm that the model applies to the real world and develop practical skills required for examinations, since recent reviews recommend integrating simulations with appropriate teacher guidance and complementary practical activities (Banda & Nzabahimana, 2021; Ramaila, 2024).

5. Keep the focus on reasoning. Ask students to explain their predictions and observations in words before introducing formulas.

6. Use the messaging group wisely. Share short videos and practice questions after class, keeping file sizes small to limit students' data costs, and provide printed copies for students without phones.

7. Ensure safety. Use only low-voltage dry cells for student circuits and demonstrate mains-related concepts through video rather than live experiments.

Plan for Evaluation The effectiveness of the package will be evaluated through a quasi-experimental, nonequivalent pretest-posttest control group design in senior secondary schools. Intact SS II physics classes will be assigned to an experimental group taught with the package and a control group taught with the conventional method, over the six units.

Instruments. Conceptual understanding will be measured with an electricity concept test adapted from established diagnostic tests of direct-current circuit concepts (Engelhardt & Beichner, 2004) and validated for the Nigerian curriculum. Students' interest and attitudes will be measured with a rating scale, and teachers' experiences will be captured through interviews and lesson observation.

Analysis. Analysis of covariance, with pretest scores as covariates, will compare posttest conceptual understanding between groups. Item-level analysis will show which misconceptions changed. Effects by gender and school location will also be examined.

Qualitative data from teachers will be analysed thematically to refine the package.

Expected Benefits and Limitations The package is expected to make abstract electricity concepts visible, address persistent misconceptions, increase student engagement and allow schools with poorly equipped laboratories to offer meaningful, inquiry-based physics instruction at low cost. It also builds teachers' capacity to integrate ICT purposefully.

The package has limitations. It still requires at least one functioning device and some form of power, which not all schools have. Simulations simplify reality and cannot replace hands-on practical skills. Its effectiveness depends heavily on teachers' preparation and pedagogical skill, and its impact has yet to be confirmed through the planned evaluation, reflecting wider cautions that technology is not automatically effective and that equitable access, teacher capacity and evidence of impact matter (Srinivasan et al., 2024; UNESCO, 2023).

Conclusion Electricity is a foundational yet difficult topic in physics, and Nigerian students' learning of it is hindered by invisible concepts, persistent misconceptions and poorly equipped laboratories. This paper has presented a low-cost ICT instructional package that combines free offline simulations, smartphone tools, teacher-made videos, simple display and power solutions, low-cost circuit kits and messaging-application support, organised into six predict-observe-explain units targeting documented misconceptions. Grounded in constructivism, multimedia learning theory and TPACK, and developed through the ADDIE model, the package shows that effective ICT integration in physics need not depend on expensive technology, provided that low-cost tools are deliberately aligned with learning goals and supported by teachers. What matters most is the purposeful alignment of simple tools with specific concepts and sound pedagogy.

RECOMMENDATIONS

1. Physics teachers should adopt low-cost ICT tools, particularly offline simulations and smartphone videos, to make electricity concepts visible and to challenge misconceptions through predict-observe-explain activities.

2. School administrators should provide at least one projector or display device, a laptop and solar backup per school for physics teaching.

3. Government agencies, teacher professional bodies and TETFund-supported institutions should organise hands-on workshops training physics teachers to use the package and similar resources.

4. Teacher education institutions should incorporate low-cost ICT and simulationbased pedagogy into pre-service physics teacher training.

5. Curriculum developers should recommend specific free simulations and ICT activities in the physics curriculum and teachers' guides.

6. Researchers should carry out the planned evaluation and extend the package design to other abstract physics topics such as electromagnetism, waves and modern physics.

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