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Transforming Low-Voltage Circuit Measurement into Real-Time Inquiry: Pedagogical Design and Teacher Appraisal of an ESP32-Phyphox System

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Abstract: **This study reinterprets a student research project on ESP32- and Phyphox-assisted circuit experiments from a pedagogical rather than only a technical perspective. The purpose was to formulate a classroom-use model in which low-voltage measurements of current, voltage and power become real-time evidence for inquiry in Grade 11 Physics. The system used an ESP32 microcontroller, a digital current/power sensor and the Phyphox mobile application to display numerical values and graphs on a smartphone. A design-based procedure was used: classroom needs were identified, the measurement system was translated into inquiry phases, and five high-school physics teachers appraised its readiness for teaching. Teacher responses showed that conventional circuit experiments were limited mainly by lack of equipment, difficulty observing variation of data, and difficulty drawing graphs during class. The proposed model therefore emphasized prediction, live data capture, graph interpretation, and evidence-based discussion. Teacher appraisal was positive, with mean scores of 4.38/5 for technical characteristics, 4.32/5 for time and classroom organization, 4.54/5 for pedagogical value, and 4.60/5 for practical applicability. The findings indicate that the ESP32-Phyphox system can function as a didactic bridge between circuit manipulation and scientific reasoning. Further classroom trials with students are needed before claims about learning effectiveness can be generalized.**

Keywords: **ESP32; Phyphox; real-time data; electric circuits; inquiry-based learning; digital sensor; physics education.**

I. INTRODUCTION

Practical work is an essential component of physics education because it allows learners to connect observable events with scientific concepts, manipulate variables and use evidence in forming explanations [1], [2]. In the topic of electric current and circuits, this connection is especially important. Students are expected not only to state relationships among voltage, current, resistance and power, but also to interpret these relationships through measured values and graphs.

In many school laboratories, however, electric-circuit experiments remain strongly dependent on separate voltmeters, ammeters, manual recording tables and graph drawing after the measurement. These procedures are valuable for basic measuring skills, but they can make the experimental process fragmented. When a learner changes the circuit condition, the relation between the physical manipulation, the changing readings and the resulting graph may not be visible immediately. This weakens the opportunity for inquiry because students spend substantial time copying values instead of discussing patterns.

Mobile technology and open microcontroller platforms offer a possible response to this problem. Phyphox provides mobile tools for collecting, displaying and exporting experimental data [3], while recent Phyphox-Arduino work has made it easier to connect external sensors through Bluetooth Low Energy [4]. ESP32 is also suitable for school devices because it integrates Wi-Fi and Bluetooth functions in a compact microcontroller platform [5]. When combined with a digital current/power sensor such as INA219, which provides current, bus voltage and power readings through an I2C-compatible interface [6], the smartphone can become a real-time display and analysis station rather than only a built-in sensor package.

A previous manuscript prepared from the same broader research project focused mainly on the design and general evaluation of ESP32- and Phyphox-based experiments. The present article takes a different research angle. It examines how the measurement system can be transformed into an inquiry-oriented teaching model for low-voltage circuit experiments, what classroom needs this model addresses, and what implementation conditions must be satisfied for use in Grade 11 Physics. The research questions were: (1) What barriers in existing circuit experiments justify a real-time digital measurement approach? (2) How can the ESP32-Phyphox system be organized as an inquiry sequence? (3) How do physics teachers appraise its classroom readiness and what safeguards are needed for implementation?

II. PEDAGOGICAL RATIONALE

A. From practical work to inquiry

The educational value of an experiment is not determined only by the existence of apparatus. Practical work becomes meaningful when students are guided to observe, compare, interpret and relate what they see to scientific ideas [2]. In circuit experiments, this means that the learner should be able to notice how current changes when voltage or resistance changes, then use the observed relation to reason about Ohm law, source behavior or electric power.

A real-time display can support this process by reducing the time gap between manipulation and interpretation. When a graph appears while the circuit is being adjusted, a teacher can ask students to predict the next trend, check the prediction immediately, and discuss why the data behave as they do. The graph is therefore not a final product drawn after the lesson but a shared object for discussion during the lesson.

B. Digital mediation in low-voltage circuit learning

The proposed learning model does not replace the physical circuit with a simulation. Students still connect components and change real circuit conditions. The digital layer has a different role: it synchronizes measurement, visualization and data export. This distinction is important pedagogically because the learner deals with a real electrical system while receiving richer feedback than that provided by isolated meter readings.

For Grade 11 Physics, three content clusters are especially compatible with this approach: the volt-ampere characteristic and Ohm law; the relationship between terminal voltage and current in a closed circuit; and the real-time relation P = UI for power and energy discussions. The learning emphasis is not on advanced programming, but on using data streams as evidence for physics reasoning.

TABLE I: TRANSLATING THE DIGITAL MEASUREMENT SYSTEM INTO INQUIRY LEARNING ACTIONS

Inquiry phase	Teacher action	Student action	Role of real-time data
Problem situation	Pose a question such as how current changes when voltage is varied.	State initial ideas and expected trends.	Makes the target relation explicit before measurement.
Prediction	Ask students to sketch or describe the expected U-I relation.	Predict linear or non-linear behavior and justify the prediction.	Creates a baseline for later comparison.
Circuit manipulation	Guide safe low-voltage connection and adjustment of the circuit.	Change voltage, resistance or load under supervision.	Links physical action directly with changing readings.
Live observation	Project or observe Phyphox values and graphs.	Identify stable regions, noise, slope and data trends.	Turns data into a common visual object for discussion.
Evidence-based conclusion	Relate the graph to U = RI, U = E - rI or P = UI.	Use measured patterns to support or correct explanations.	Supports reasoning from evidence rather than memorization.
Extension	Ask learners to compare loads or design a STEM task.	Apply the same data logic to a new circuit problem.	Supports transfer beyond a single verification experiment.

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III. MATERIALS AND METHODS

A. Research design

The study used a design-based research orientation. The work began with analysis of difficulties in teaching electric-current and circuit experiments, followed by development of a low-voltage ESP32-Phyphox measurement system and conversion of this system into classroom activities. The final stage was teacher appraisal of the product and its use model.

The article deliberately emphasizes pedagogical conversion and implementation readiness. Technical construction details are summarized only to the extent needed to understand the teaching model.

B. Apparatus and learning tasks

The apparatus included an ESP32 board, a digital current/power sensor, a low-voltage source, circuit loads and a smartphone with Phyphox installed. The sensor measured electrical quantities in the circuit, the ESP32 collected and transmitted the values, and Phyphox displayed numerical data and graphs. The setup was intended for low-voltage educational circuits and teacher-supervised use.

Three classroom applications were considered. The first was the volt-ampere characteristic of a resistor for Ohm-law verification. The second was the closed-circuit experiment for determining electromotive force and internal resistance through the relation between terminal voltage and current. The third was an extension activity on electrical power and energy consumption in real time.

C. Participants and data processing

Five high-school physics teachers participated in the appraisal stage. Three had at least 15 years of experience, one had 10 to under 15 years of experience, and one had 5 to under 10 years of experience. All had experience teaching the topic of electric current and circuits.

The questionnaire contained items on existing barriers, technical characteristics, time and classroom organization, pedagogical value, practical applicability and suitable forms of use. Frequencies, percentages and mean scores were calculated. Since the number of teachers was small, the findings are interpreted as preliminary evidence for product refinement rather than as a statistical generalization.

IV. RESULTS

A. Classroom needs for real-time circuit data

Teacher responses indicated that the main problems were not only the shortage of apparatus but also the limited visibility and processability of data during the lesson. Four out of five teachers reported lack of experimental equipment and students' difficulty observing changes in data. Three out of five reported old or insufficiently accurate equipment, difficulty drawing graphs and processing data in class, and difficulty organizing group experiments. No teacher selected electrical safety as a major barrier in the surveyed low-voltage teaching context.

TABLE II: TEACHER-REPORTED BARRIERS IN CURRENT AND CIRCUIT EXPERIMENTS

Barrier	Number of teachers	Percentage (%)	Pedagogical implication
Lack of experimental equipment	4/5	80	Limits opportunities for regular hands-on work.
Students have difficulty observing data variation	4/5	80	Weakens the link between manipulation and concept formation.
Old or insufficiently accurate equipment	3/5	60	Reduces trust in measured evidence.
Difficulty drawing graphs and processing data in class	3/5	60	Moves interpretation outside the immediate experimental moment.
Difficulty organizing group experiments	3/5	60	Restricts student participation and collaboration.
Time-consuming setup and measurement	1/5	20	Can reduce the inquiry time in a lesson.
Concern about electrical safety	0/5	0	Not the dominant concern for low-voltage classroom circuits in this sample.

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B. Inquiry protocol produced from the system

The most direct activity was the volt-ampere experiment. Instead of asking students only to fill a static table, the teacher can organize the activity around a changing graph. Students first predict the graph for a resistor. They then adjust the circuit and observe whether the U-I points form a straight trend. The slope is interpreted as resistance, and deviations can be used to discuss measurement error, contact quality or heating effects.

In the closed-circuit activity, students observe that terminal voltage decreases when current increases. The relation $U = E - rI$ can be treated as a graph-reading problem: the intercept represents electromotive force and the absolute value of the slope represents internal resistance. This activity is more demanding than the Ohm-law activity because students must interpret a negative slope and distinguish ideal and real sources.

For power and energy extension, the same apparatus can be used to display power as $P = UI$ and to discuss practical questions such as how different loads consume electrical energy. This activity is suitable for STEM or student research tasks because it connects circuit quantities with everyday energy use.

C. Teacher appraisal of classroom readiness

Teacher appraisal was positive in all criterion groups. Practical applicability obtained the highest mean score, followed by pedagogical value. This suggests that teachers saw the system not merely as a technological product but as a tool that could support visualization, discussion and evidence-based reasoning in ordinary physics lessons.

TABLE III: TEACHER APPRAISAL IN TERMS OF CLASSROOM READINESS

Criterion group	Mean score	Ratings at level 4-5 (%)	Interpretation for implementation
Technical characteristics	4.38/5	98.0	The device was considered compact and capable of measuring necessary quantities with teaching-level accuracy.
Time, operations and class organization	4.32/5	98.0	The activity is feasible, but initial connection routines and familiarization are needed.
Pedagogical value	4.54/5	100.0	The strongest affordance is real-time visualization for experimental competence and discussion.
Practical applicability	4.60/5	100.0	The product has potential for high-school use if accompanied by guidelines, equipment and procedures.

D. Recommended modes of use

The teachers did not recommend a single fixed use mode. All five teachers selected use in practical or verification lessons; four selected teacher demonstration; three selected small-group experiments; and two selected STEM or student research use. These results show that the same device can serve different levels of student participation.

TABLE IV: RECOMMENDED IMPLEMENTATION MODES

Mode of use	Teacher selections	Percentage (%)	Most suitable function
Practical or verification lesson	5/5	100	Help students verify laws and interpret graphs within the lesson.
Teacher demonstration	4/5	80	Introduce a phenomenon quickly and project real-time data for the whole class.
Small-group experiment	3/5	60	Allow students to manipulate circuits and discuss evidence collaboratively.
STEM or student research activity	2/5	40	Extend circuit measurement toward energy monitoring or product improvement.

V. DISCUSSION

A. Added value of the pedagogical model

The main contribution of the study is the translation of a digital measurement system into a classroom inquiry structure. The device is useful not because it is modern, but because it changes the timing and visibility of evidence. In a conventional lesson, students may draw the graph after completing all readings; in the proposed model, the graph appears during manipulation. This allows prediction, observation, correction and explanation to occur in a tighter learning cycle.

This feature is consistent with the view that practical work should help students bridge the observable domain and the domain of ideas [2]. In electric circuits, learners often manipulate components without fully understanding how the numbers represent energy transfer or charge flow. Real-time graphs can make this bridge more explicit when the teacher asks learners to explain what each point, slope or intercept means physically.

B. Conditions for safe and sustainable implementation

Several conditions must be satisfied before wider classroom use. First, the hardware should be enclosed in a durable case with clearly marked terminals to reduce wiring errors. Second, a short operating guide and a troubleshooting sheet should accompany the apparatus so that teachers can connect the device quickly. Third, calibration should be checked against a standard meter within the intended teaching range. Fourth, if students are not allowed to use personal phones, the teacher can use one central smartphone or tablet and project the Phyphox display.

The apparatus should remain within low-voltage educational circuits. The point of the system is not to monitor household mains power in school laboratories, but to create a safe and data-rich environment for learning basic circuit relations. For activities that involve power and energy, teachers should use low-voltage loads and frame the discussion conceptually rather than attempting high-voltage measurement.

C. Limitations

The results have three limitations. The appraisal sample contained only five teachers, so the data represent an initial product-evaluation stage. The study did not include a controlled student learning experiment, so it cannot claim that the model improves achievement compared with traditional methods. Finally, technical performance was evaluated for educational suitability, but future studies should report calibration curves, uncertainty estimates and long-term stability more rigorously.

Future work should therefore include classroom trials with students, pre-test and post-test evidence, comparison among different implementation modes, and refinement of the hardware package. Student interviews would also help clarify whether real-time data actually improves conceptual links or only increases interest.

VI. CONCLUSION

This article presented a pedagogical model for using an ESP32 microcontroller, a digital current/power sensor and Phyphox in Grade 11 electric-current and circuit experiments. Unlike a purely technical report, the focus was on how real-time measurement can be organized into prediction, observation, graph interpretation and evidence-based conclusion. Teacher responses showed that the system addresses common classroom barriers such as limited apparatus, low visibility of data variation and difficulty processing graphs during class.

The teacher appraisal results suggest that the model is promising for practical lessons, teacher demonstration, group experiments and STEM extension. Its strongest value lies in making measured data visible at the moment when the circuit is being manipulated. Nevertheless, the product should be accompanied by clear operating instructions, low-voltage safety rules, calibration procedures and a more robust physical design. Larger classroom studies are necessary before drawing strong conclusions about learning outcomes.

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REFERENCES

[1] A. Hofstein and V. N. Lunetta, "The laboratory in science education: Foundations for the twenty-first century," Science Education, vol. 88, no. 1, pp. 28-54, 2004, doi: 10.1002/sce.10106.

[2] I. Abrahams and R. Millar, "Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science," International Journal of Science Education, vol. 30, no. 14, pp. 1945-1969, 2008, doi: 10.1080/09500690701749305.

[3] S. Staacks, S. Hütz, H. Heinke, and C. Stampfer, "Advanced tools for smartphone-based experiments: phyphox," Physics Education, vol. 53, no. 4, article 045009, 2018, doi: 10.1088/1361-6552/aac05e.

[4] S. Staacks, D. Dorsel, A. Krampe, M. Hagedorn, E. Leier, H. Heinke, and C. Stampfer, "Bluetooth sensors in phyphox with Arduino and MicroPython: paving the way from an idea to an experiment for teachers and learners," Physics Education, vol. 60, no. 3, article 035014, 2025, doi: 10.1088/1361-6552/adbf5f.

[5] Espressif Systems, "ESP32 Wi-Fi & Bluetooth SoC," Espressif Systems, 2026. [Online]. Available: https://www.espressif.com/en/products/socs/esp32

[6] Texas Instruments, "INA219 Zerø-Drift, Bidirectional Current/Power Monitor With I2C Interface," Data Sheet SBOS448G, revised Dec. 2015.

[7] K. Hochberg, J. Kuhn, and A. Müller, "Using smartphones as experimental tools—effects on interest, curiosity, and learning in physics education," Journal of Science Education and Technology, vol. 27, no. 5, pp. 385-403, 2018, doi: 10.1007/s10956-018-9731-7.

[8] D. B. Thao and D. T. Q. Thi, "Giải pháp sử dụng smartphone giúp học sinh học trực tuyến thí nghiệm Vật lý lớp 10," Can Tho University Journal of Science, vol. 58, Special issue: Education in the Mekong Delta, pp. 84-90, 2022, doi: 10.22144/ctu.jvn.2022.154.

[9] Phyphox Team, "phyphox - Physical Phone Experiments," RWTH Aachen University, 2026. [Online]. Available: https://phyphox.org/

[10] Phyphox Team, "phyphox Arduino BLE," GitHub repository, 2026. [Online]. Available: https://github.com/phyphox/phyphox-arduino

[11] Research Publish Journals, "Research Paper Preparation Guidelines For Journals And Conferences," 2026. [Online]. Available:https://www.researchpublish.com/page/Research-Paper-Preparation-Guidelines-for-Journals-and-Conferences