



The Impact of Inquiry-Based Physics Laboratory Interventions on High School Learners' Conceptual Understanding of Direct Current Circuits

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Introduction/Abstract

Abstract. This study investigated the impact of hands-on practical activities on 33 high school learners' conceptual understanding of series and parallel circuits, as well as their engagement with scientific inquiry, during an educational outreach visit to a tertiary institution's physics laboratory. Using a pretest-posttest design, the study assessed learners' comprehension of fundamental electrical concepts: including current, voltage, resistance, and circuit modifications while also exploring their perceptions of inquiry-based practical work. The findings revealed that despite participating in university-level experimentation, learners demonstrated limited improvements in their conceptual understanding, particularly regarding the complex relationships among current, voltage, and resistance. However, the laboratory activities significantly supported the development of analytical reasoning and fostered a robust understanding of the nature of scientific inquiry, with most learners recognizing experiments as vital tools for hypothesis testing, data collection, and explaining natural phenomena. Furthermore, learners generally perceived the outreach sessions as highly beneficial to their learning experience. The study concludes that while short-term tertiary laboratory visits may produce constrained gains in immediate conceptual mastery, such inquiry-based interventions remain an essential pedagogical approach for promoting scientific literacy, analytical skills, and active learner participation in physical science education.

Introduction. Direct current (DC) electricity is a cornerstone of the physical sciences curriculum and a foundation for engineering pathways (Vera & Rivera, 2023), yet abstract quantities such as potential difference, current and resistance remain difficult for learners, and teacher-centred instruction often leaves fragmented knowledge. Outreach programmes at tertiary institutions give learners access to authentic laboratories for inquiry-based work (Mubark & Kriek, 2023), but direct contact with equipment does not automatically resolve conceptual difficulties. **Aim:** to investigate the impact of a short-term, inquiry-based laboratory intervention on high school learners' understanding of series and parallel circuits and their scientific literacy.

Experimental/Theory

Research questions

- RQ1:** To what extent does an inquiry-based laboratory intervention improve learners' schematic component identification?
- RQ2:** How do hands-on sessions influence understanding of foundational principles (current, voltage, resistance, component roles)?
- RQ3:** How do they affect learners' ability to evaluate circuit topologies across diagrammatic and physical configurations?

Method

Quantitative pretest-posttest design with 33 high school learners on an outreach visit to a university physics laboratory. Learners used real batteries, ammeters, voltmeters, wires and bulbs (no simulations) to form hypotheses, build series and parallel circuits, vary variables, observe bulb brightness and read meters.

A researcher-designed diagnostic test (15 sub-questions) covered **Section A**, schematic component identification (4); **Section B**, foundational DC principles (6); and **Section C**, system topology and network dynamics (5). Pre and post scores were compared overall and by section.

Theoretical framework

- Cognitive Load Theory** (Sweller, 1988): tangled wiring and instrument placement can exhaust finite working memory, leaving little capacity for germane processing.
- Representational competence** (Kozma & Russell, 2005): idealised 2D schematics and real 3D hardware are often treated as unlinked (Engels & Shaffer, 2003).
- Guided inquiry** (Hmelo-Silver et al., 2007; Vygotsky, 1978): without scaffolding, practical work can reinforce alternative frameworks (Ramnarain & Moosa, 2017).

Results/Discussions

Section / sub-question	Pretest (%)	Posttest (%)	Shift (pts)
Section A: Schematic component identification	86.1	90.2	+4.1
Resistor / bulb	100	97	-3.0
Battery / cell	66.7	84.8	+18.1
Conductor / wire	100	97	-3.0
Switch	77.8	81.8	+4.0
Section B: Foundational DC principles	61.2	64.2	+3.0
Role of the battery	84.8	84.8	0.0
Role of the switch	57.6	48.5	-9.1
Resistors in series	51.5	48.5	-3.0
Ammeter connections	69.7	57.6	-12.1
Role of the resistor	48.5	72.7	+24.2
Battery / cell relation	60.6	51.5	-9.1
Section C: Topology and network dynamics	61.2	64.2	+3.0
Removing a bulb: series circuit	27.3	33.3	+6.0
Removing a bulb: parallel circuit	57.6	57.6	0.0
Current in series & parallel circuits	63.6	78.8	+15.2
Physical representations	60.6	51.5	-9.1
Symbolic representations	97	100	+3.0

Table 1: Pre- and posttest mean scores (%) and net shift in percentage points, by section and sub-question (n = 33).

Symbolic vs physical representations (RQ1 & RQ3). Learners reached 100% on idealised 2D schematics, yet accuracy on physical circuit identification with real wires, batteries and bulbs fell 9.1 points to 51.5%. Overlapping wires, varied orientation and terminal placement appear to overload working memory (Sweller, 1988) and expose weak transfer between representations (Kozma & Russell, 2005; Engels & Shaffer, 2003).

Isolated gains vs regressions (RQ2). Seeing bulb brightness change supported gains in the role of the resistor (+24.2) and current in series and parallel circuits (+15.2). Regressions in ammeter connections (-12.1) and the role of the switch (-9.1) suggest uncorrected errors, such as connecting an ammeter in parallel, can cement misconceptions (Ramnarain & Moosa, 2017). Removing a bulb in a parallel circuit did not change (57.6%), consistent with persistent “local reasoning” models (Vera & Rivera, 2023).

Key Findings

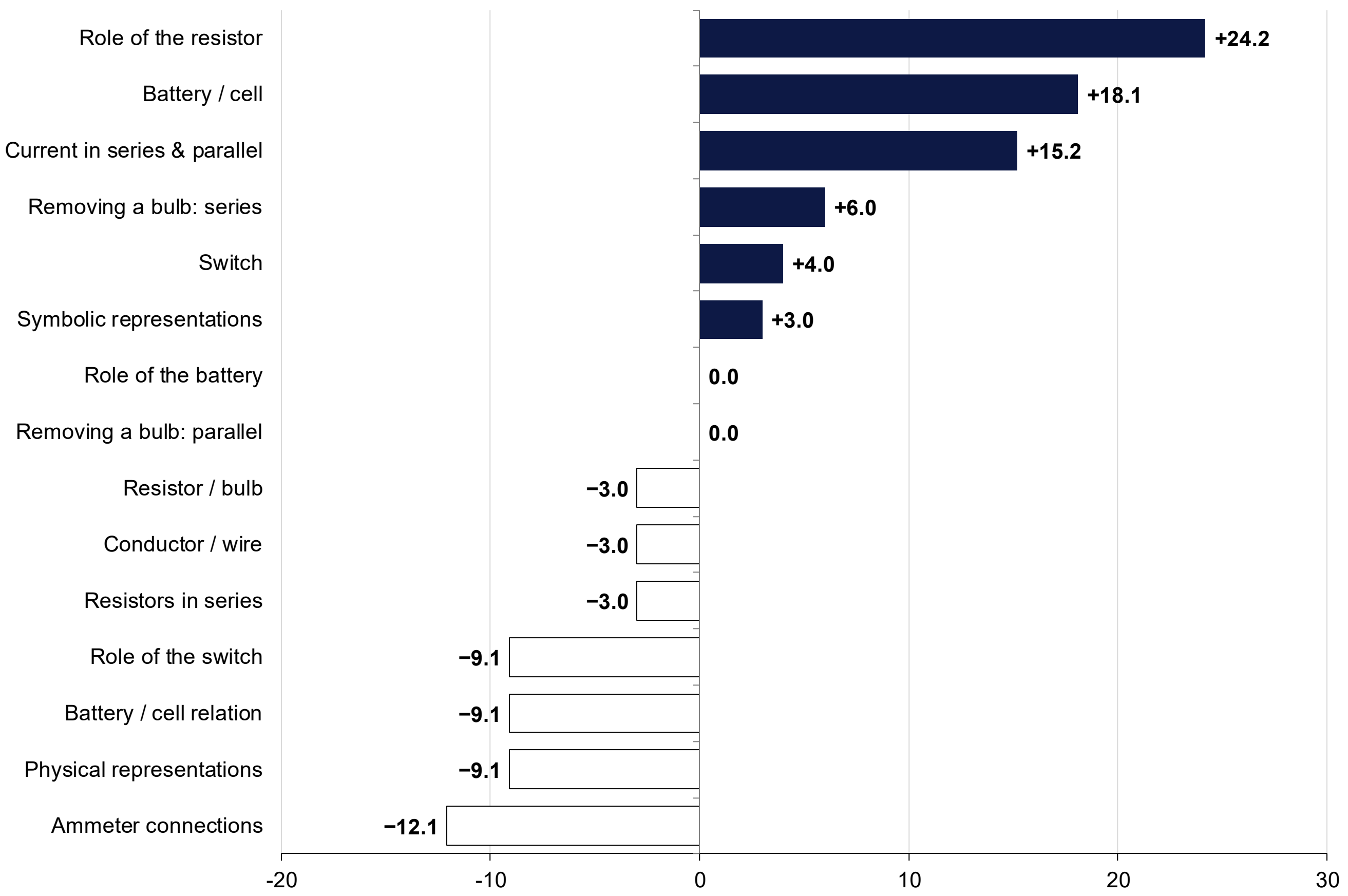


Figure 1: Net shift in mean score (posttest – pretest, percentage points) for each sub-question (n = 33). Navy bars show gains; orange bars show regressions.

Conclusions

- Schematic competency (RQ1):** high baseline symbol decoding (86.1%) rose only marginally to 90.2%; symbolic fluency operates independently of practical operational competency.
- Foundational principles (RQ2):** isolated gains (resistor role +24.2) alongside regressions in procedural areas such as ammeter integration (-12.1) and switch mechanics (-9.1).
- Topology and dynamics (RQ3):** 100% accuracy on diagrams, but physical series/parallel identification fell 9.1 points to 51.5%.

Short tertiary laboratory visits foster scientific literacy and active participation, but yield constrained gains in immediate conceptual mastery when delivered as isolated events.

Recommendations

- Scaffold across representations: map physical wires and terminals back to schematics.
- Use hybrid simulations (e.g. PhET) before physical labs (Mubark & Kriek, 2023).
- Embed predictive checkpoints and real-time formative assessment.
- Move from single events to sustained interventions with pre-visit preparation and post-visit debriefs.

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