Addressing Learning Difficulties with Circuits: An *"Aufbau*"* Approach

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* *"Aufbau"* = "building up" as in, e.g., atomic physics.

Research on Learning of Electric Circuit Concepts

- **Pre-college students**
  - Shipstone (1984)
- **Early work with college students**
  - Fredette and Lochhead (1980)
  - Cohen, Eylon and Ganiel (1982)
- **Extended investigations with college students**
  - Shaffer and McDermott (1992)
  - Harrington (1995)

General Conceptual Problems with Circuits

- Students retain confusion with “building block” concepts such as charge, field, potential, etc.

- Students struggle with common ***representations*** of circuits e.g., relating circuit diagrams to drawings, and drawings to actual equipment

- Students do not have separate concepts attached to the words “current,” “power,” “energy,” and “voltage.” *(it’s all “electricity”)*

  This exacerbates tendency toward confusion

  - “batteries have constant *current*” [instead of *voltage*]
  - “*current* gets used up in circuit elements” [instead of *energy*]

The two ***most universal*** conceptual difficulties regarding circuits:

- Most students believe strongly that electric current gets *used up* as it moves through circuit elements.

- The overwhelming majority of students are ***certain*** that a battery will always produce the same amount of current *regardless of the circuit to which it is attached.*

It is EXTREMELY DIFFICULT to persuade students that these ideas are not correct!

Key Conceptual Obstacles ***Before*** Confronting Circuits

[when using traditional sequence of topics]

- Understanding concept of *"potential"*
- Distinguishing between *"potential"* and *"potential difference"*
- Understanding concepts of *"current"* and *"resistance"*
- Realizing that potential *decreases* as positive charges flow through a resistor
- Recognizing that ***energy*** *(**not** current)* is "used up" in resistors
- Realizing that current flow is proportional to *potential* ***difference*** *(**not** potential)*
- Recognizing that an "ideal" conducting wire is an equipotential volume

Key Conceptual Obstacles ***<u>Specific</u>*** to Complete Circuits

(related to ***global*** characteristics)

- Sum of potential changes in a closed current loop equals zero
- (Ideal) battery provides constant potential difference, but ***<u>varying</u>*** amounts of current
- Current flowing out of battery may “split up” into multiple pathways and then recombine ***(to original magnitude)*** before re-entering battery

“Current First” Instructional Strategy
(University of Washington, PEG)

[“Physics By Inquiry” *and “**Tutorials in Introductory Physics”:*** *Extended hands-on investigations using batteries and bulbs.]*

1) Introduce concept of complete circuit: *try to light bulb with wire and battery*

2) Introduce concept of current: *current not “used up”; current through a battery depends on circuit configuration.*

3) Introduce concepts of resistance and equivalent resistance

4) Introduce ammeters, voltmeters, and concept of potential difference.

5) Finally, introduce concepts of energy and power.

Advantages of “Current First” Strategy

[Cf. Shaffer & McDermott, 1992]

- Avoids need for immediate grappling with “potential” concept.
- Notion of “flow” relatively easy for students to accept.
- Averts probable early confusion of “energy loss” with current “non-conservation.”
- Allows much deduction and model-building based on ***qualitative*** observation.

$\rightarrow$ *But what if there is* ***no*** *laboratory and* ***no*** *recitation available?* ¬

Characteristics of This Course

- Algebra-based general physics course (at Southeastern Louisiana University)
- All activities involved pencil & paper work in lecture hall (group and individual work)
- Laboratory ***not required***; most students took completely traditional laboratory (independent of lectures)

Another Strategy: Emphasis on Potential

“Workbook for Introductory Physics” *by Meltzer and Manivannan; for in-class use without relying on lab. Used* ***Fall 1997*** *and* ***Spring 1998****.*

Both semesters: Extended development of electric forces and fields, electric potential energy, and electric potential;

Fall 1997: Study of ***complete*** circuits merged with current and Ohm’s law concepts (introduced same day);

Spring 1998: Intensive study of current, “voltage,” and Ohm’s law ***before*** discussion of circuits; examination of circuit segments “builds up” to complete circuits;

Both semesters: Step-by-step analysis of ***very simple*** circuits.

Circuit Diagnostic Question Set

(Four-item quiz, with virtually identical questions presented in four different forms [word problem, “math” problem; diagrammatic problem, graphical problem]).

Question #2:

Parallel circuit: *battery = V volts;* $R_A = 6\Omega$; $R_B = 9\Omega$.

Series circuit: *battery = V volts;* $R_C = 7\Omega$; $R_D = 3\Omega$.

® A. $\dfrac{\mathbf{I_B}}{\mathbf{I_C}} > 1$

C. $\dfrac{I_B}{I_C} < 1$

B. $\dfrac{I_B}{I_C} = 1$

D. $\dfrac{I_B}{I_C} = -1$

Comparative Performance on Four-item Diagnostic

- Fall, 1997 (N= 60)

  Mean score out of 4: 2.0 ± 0.2

- Spring, 1998 (N= 58)

  Mean score out of 4: 2.8 ± 0.2

[significant improvement, $p < 0.001$]

Other Assessment Questions

- **[Ohm's law]** *Two identical resistors are carrying an electric current; the electric potential at the left end of each resistor is 6 V. The potential at the right end of resistor "A" is 12 V, and the potential at the right end of resistor "B" is 9 V. If 4 A flows through resistor "A," how much current flows through resistor "B"?* **[Answer: 2 A]**

- **[Series Circuit]** *A 2-ohm resistor and a 1-ohm resistor are connected in series with a 9-V battery. What is the voltage drop across the 2-ohm resistor?* **[Answer: 6 V]**

- **[Parallel Circuit]** *A 3-ohm, a 6-ohm, and a 9-ohm resistor are connected in parallel with a 6-V battery. Which of the resistors will have the most charges flowing through it each second?* **[Answer: the 3-ohm resistor]**

Comparative Results on Other Assessment Questions

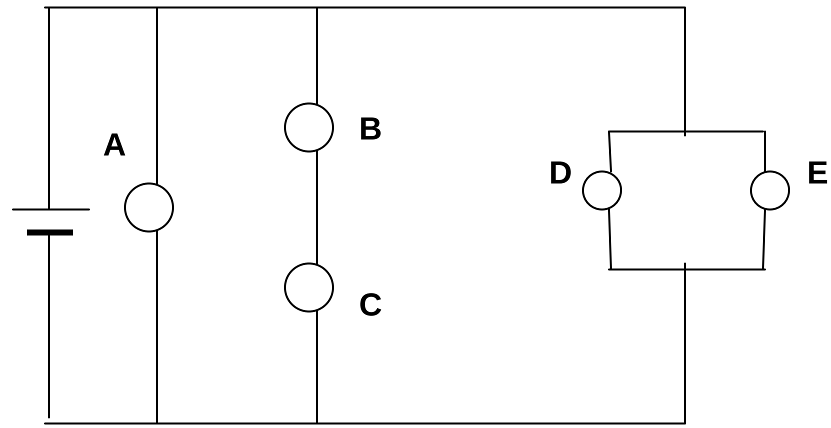
(given on final exam)

	(correct responses)	
	Fall 1997	**Spring 1998**
	(N = 61)	***(N = 61)***
Ohm's law	67%	67%
Series Circuit	79%	84%
Parallel Circuit	89%	90%

Final Assessment Question #1

(given on final exam, Spring 1998)

The circles in this diagram represent ***identical*** light bulbs.



Rank, in order, the following:

A. The brightness of bulb “A”

B. The brightness of bulb “B”

C. The brightness of bulb “C”

D. The brightness of bulb “D”

E. The brightness of bulb “E”

[Answer: A = D = E > B = C]

This class *(algebra-based physics, N = 61)*:

59% correct responses

Traditional instructional *(calculus-based)*:

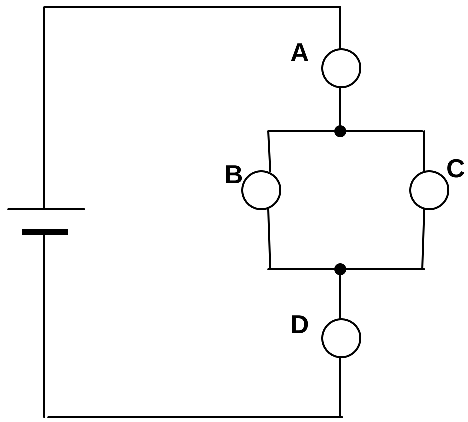
15% correct responses

[reported by *Shaffer & McDermott, 1992*]

Final Assessment Question #2

(given on final exam, Spring 1998)

The circles in this diagram represent ***identical*** light bulbs.



Rank, in order, the following:

A. The brightness of bulb “A”

B. The brightness of bulb “B”

C. The brightness of bulb “C”

D. The brightness of bulb “D”

Explain your reasoning.

[Answer: A = D > B = C]

Results *(algebra-based physics; N = 61):*

54% correct with correct explanation;

20% : A > D ***because*** “the voltage is less at D”

15% : B = C > A = D ***because*** “B & C are in parallel”

8% : A = B = C = D

3% correct with incorrect (or missing) explanation;

Highlights of Assessment Data

*(**Note:** No “bulb brightness” problems given **during** course; only on final exam)*

- Higher rate of correct responses than in traditional instruction (59% vs.15 % on #1; 54% vs. < 50% on #2)
- 20% of students still reflect “***current gets used up”*** misconception – less than in traditional instruction (40%) but more than in tutorial instruction (5-10%)

[Cf. Shaffer and McDermott, 1992; Harrington, 1995]

Summary: Balance Sheet of ***"Workbook"*** Strategy

Advantages:

- close contact between circuit theory and preceding development of field, force, energy, and potential concepts
- provides an option when lab work is not required or not available

Disadvantages:

- confusion between current and potential may be aggravated
- only very simple circuit configurations are dealt with
- lack of "hands-on" a potentially fatal constraint on understanding