Intervention: Misconceptions on Charging Capacitors

By Shafiq R

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Intervention Report: Addressing Student Misconceptions on Charging and Discharging Capacitors

Prepared by: Shafiq Rasulan

Institution: Sarawak Matriculation College

1. Introduction

Understanding the behavior of capacitors during charging and discharging processes is a fundamental concept in electricity and electronics. However, misconceptions regarding the underlying physics principles are common among secondary-level students. This report documents an instructional intervention that was implemented with the goal of addressing and correcting these misconceptions in a group of five students. The structure, implementation, and evaluation of the intervention are presented in a descriptive manner to ensure that the approach is easily replicable by other educators.

2. Background and Rationale

During the delivery of lessons on the topic of capacitors, it became evident that several students harbored significant misconceptions about how capacitors charge and discharge. Through formative quizzes and classroom observations, five students were identified as consistently demonstrating flawed reasoning. For instance, some believed that voltage and charge increased linearly during the charging process, while others misapplied the concept of the time constant, assuming it represented the total time required for a capacitor to fully charge. Additional issues included incorrect use of exponential equations, confusion between unit prefixes such as microfarads and millifarads, and a general lack of attention to units and substitution in numerical problems.

Recognizing the need for timely and targeted remediation, a dedicated instructional session was planned. The goal was to clarify the theoretical foundations of capacitor behavior and reinforce them through applied practice, thus fostering conceptual understanding and improving problem-solving accuracy.

3. Methodology

The intervention involved five Malaysian Matriculation students and consisted of a 45-minute structured session. The design was based on active learning principles and incorporated a pre-test/post-test framework to quantify progress.

The assessment tools consisted of five questions requiring calculations that tested students' understanding of capacitor charging and discharging. Each question was marked out of three, with one mark awarded for correct substitution of values into the relevant equations and two marks for obtaining the correct numerical answer with appropriate units. The total score possible on each test was 15.

The intervention session began with a brief review of key equations governing capacitor behavior, including the exponential equations for charging

$$V(t) = V_0(1 - e^{-t/RC})$$

and discharging

$$V(t) = V_0 e^{-t/RC}.$$

This theoretical recap was followed by a demonstration using an online capacitor simulation tool, allowing students to visualize how voltage and current change over time. Visual cues and dynamic representations helped correct linear misconceptions and reinforced the exponential nature of capacitor behavior.

Following the demonstration, students were provided with a worksheet that featured five guided problems. The first question was solved together as a class, with the teacher modeling the reasoning and calculation process. For the remaining items, students worked independently, applying the concepts discussed. Peer discussion was encouraged during the solution phase to allow students to verbalize their reasoning and confront any remaining uncertainties.

The session concluded with a teacher-led summary, during which common errors were addressed explicitly. Immediately afterward, the same test was re-administered to assess conceptual and procedural gains.

4. Results and Data Analysis

The results of the pre-test and post-test are shown in the table below, along with the normalized gain for each student. Normalized gain is a metric that reflects the proportion of possible improvement achieved and is calculated using the formula $g = \frac{\text{Post - Pre}}{15 - \text{Pre}}$.

Student	**Pre-Test Score**	**Post-Test Score**	**Normalized Gain**
A	5	12	0.78
B	6	13	0.78
C	4	11	0.78
D	7	13	0.75
E	5	12	0.78

A clear trend of improvement is observed among all participants. The average pre-test score was 5.4, while the average post-test score rose to 12.2. The normalized gains, ranging from 0.75 to 0.78, are considered high and indicate that the intervention was effective in helping students bridge the gap in understanding.

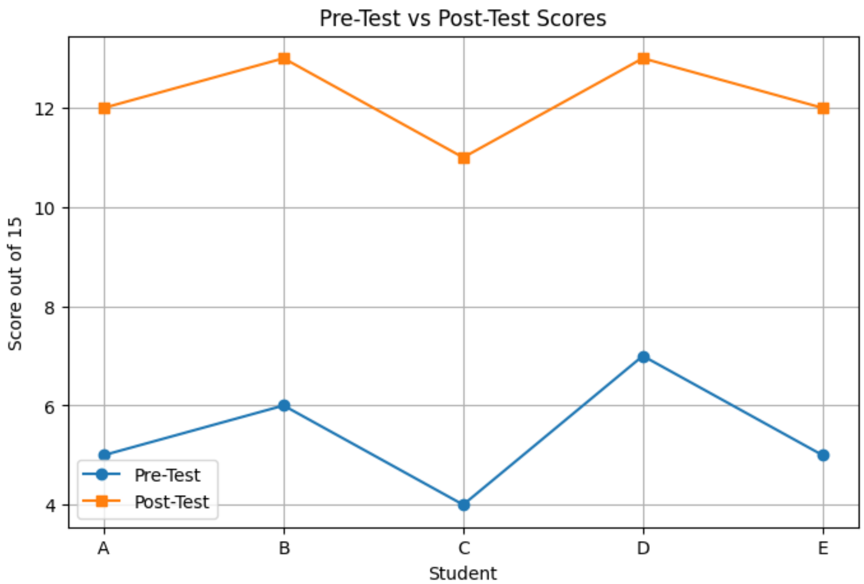

Figure 1: Comparison of Pre-Test and Post-Test Scores

5. Discussion

The outcomes of the intervention provide compelling evidence of its effectiveness. Students who initially demonstrated limited understanding were able to perform significantly better in the post-test. The use of visual simulations played a crucial role in helping students internalize the exponential nature of capacitor charging and discharging, which was previously a major point of confusion.

Guided problem-solving helped reinforce appropriate use of equations, and explicit focus was placed on the importance of units and substitution. Students also benefitted from peer discussions, which allowed them to verbalize and correct their misconceptions in a collaborative environment.

These results suggest that a combination of conceptual reinforcement, guided practice, and peer interaction can significantly improve student understanding of capacitor behavior. The high normalized gains also affirm that this approach can be considered highly effective in terms of learning impact.

6. Conclusion

This intervention successfully addressed key misconceptions related to charging and discharging capacitors. The structured, evidence-based approach led to measurable improvements in understanding, as indicated by significant gains in test scores. Importantly, this report presents a clear and replicable procedure that can be adopted or adapted by other educators facing similar challenges in their classrooms.

Appendix A: Pre and Post Test

Capacitor Charging and Discharging Worksheet

1. A 10μF capacitor is charged through a 5kΩ resistor. Find the voltage across the capacitor after 10 ms if the supply is 12V. Use the formula $V(t) = V_0(1 - e^{-t/RC})$.
2. A 22μF capacitor discharges from 6V through a 10kΩ resistor. Find the voltage after 0.1 seconds. Use the formula $V(t) = V_0 e^{-t/RC}$.
3. Calculate the time constant for a 47μF capacitor in series with a 2.2kΩ resistor.
4. How long will it take for a 1.5V capacitor to reach 63% of its maximum charge through a 3.3kΩ and 100μF setup?
5. If a capacitor reaches 90% of its maximum voltage in 5.3 seconds, estimate the time constant.

Students were instructed to show all working clearly, include correct units in final answers, and round values appropriately.

Appendix B: Marking Scheme with Step-by-Step Solutions

Question 1

A 10μF capacitor is charged through a 5kΩ resistor. Find the voltage across the capacitor after 10 ms if the supply is 12V.

- $R = 5000\ \Omega$, $C = 10 \times 10^{-6}$ F, $t = 0.01$ s, $V_0 = 12$ V
- $\tau = RC = 5000 \times 10 \times 10^{-6} = 0.05$ s
- $V(t) = V_0(1 - e^{-t/RC}) = 12(1 - e^{-0.01/0.05})$ [1 mark]
- $= 12(1 - e^{-0.2}) = 12(1 - 0.8187) = 12(0.1813)$
- $= 2.1756V \approx 2.18$ V [1 mark]
- Final answer: $\boxed{2.18 \text{ V}}$ [1 mark]

Question 2

A 22μF capacitor discharges from 6V through a 10kΩ resistor. Find the voltage after 0.1 seconds.

- $R = 10000\ \Omega$, $C = 22 \times 10^{-6}$ F, $t = 0.1$ s, $V_0 = 6$ V
- $\tau = RC = 10000 \times 22 \times 10^{-6} = 0.22$ s
- $V(t) = V_0 e^{-t/RC} = 6e^{-0.1/0.22}$ [1 mark]
- $= 6e^{-0.4545} = 6(0.6342) = 3.805$ V
- Final answer: $\boxed{3.81 \text{ V}}$ [2 marks]

Question 3

Calculate the time constant for a 47μF capacitor in series with a 2.2kΩ resistor.

- $R = 2200\ \Omega$, $C = 47 \times 10^{-6}$ F

- $\tau = RC = 2200 \times 47 \times 10^{-6}$ [1 mark]

- $= 0.1034$ s [2 marks]

- Final answer: $\boxed{0.103 \text{ s}}$

Question 4

How long will it take for a 1.5V capacitor to reach 63% of its maximum charge through a 3.3kΩ and 100μF setup?

- $R = 3300\ \Omega$, $C = 100 \times 10^{-6}$ F

- $\tau = RC = 3300 \times 100 \times 10^{-6}$ [1 mark]

- $= 0.33$ s [2 marks]

- Final answer: $\boxed{0.33 \text{ s}}$

Question 5

If a capacitor reaches 90% of its maximum voltage in 5.3 seconds, estimate the time constant.

- $V(t) = V_0(1 - e^{-t/\tau})$, so $0.9 = 1 - e^{-5.3/\tau}$

- $e^{-5.3/\tau} = 0.1$

- $-5.3/\tau = \ln(0.1) = -2.3026$ [1 mark]

- $\tau = 5.3/2.3026 = 2.3026$ s [2 marks]

- Final answer: $\boxed{2.30 \text{ s}}$

Appendix C: Use of Online Simulation

To aid students in visualizing the non-linear behavior of capacitors during charging and discharging, the PhET Interactive Simulation titled "Capacitor Lab: Basics" and a geogebra simulation titled "RC Circuit" was employed. These two simulations are used together.

During the intervention session, the simulation was projected on the classroom screen. The RC circuit simulator was set up and students observed how the capacitor charged over time after the switch was closed. The voltage across the capacitor and the current in the circuit were shown as changing dynamically, which helped dispel the misconception that these quantities vary linearly.

Different values of resistance and capacitance were tested to show how the time constant $\tau = RC$ affects the charging curve. Students were asked to predict outcomes before changes were made, encouraging active engagement. The instructor paused periodically to connect observed behavior with the mathematical form of the equations introduced earlier. Finally, students were invited to interact with the simulator individually during the worksheet phase, reinforcing learning through experimentation.

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