Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45335

BOARD #133: Improving Student Understanding of Electric Circuits Through Real-World Analogies

Dr. Christopher Horne, North Carolina A&T State University (CoE)

Dr. Christopher Horne, PE has been a Teaching Instructor/Lecturer at NC A&T State University and East Carolina University since 2011. He currently teaches freshman a course in problem solving using MATLAB and Electric Circuits I to underrepresented sophomores and junior engineering students. He is an ACUE certified college instructor in the STEM field who takes complicated concepts and breaks them down for undergraduate students.

Work-in-Progress (WIP): Improving Student Understanding of Electric Circuits Through Real-World Analogies

Abstract

Many engineering students struggle with Electric Circuits due to misconceptions and anxiety, which have worsened post-pandemic. Concepts like voltage, current, and Ohm's Law often seem abstract, hindering comprehension. This work-in-progress introduces the Circuit Teaching with Real-World Analogies (CTRWA) framework, which applies relatable analogies such as a water tank for voltage and current to improve understanding. Data from 50 students were collected through surveys, quizzes, and interviews, revealing that water-based analogies were the most effective, while others, such as the running track analogy, had mixed success. Preliminary results indicate that students taught with analogies scored 12% higher on quizzes and reported greater confidence in circuit analysis. While CTRWA enhances conceptual learning for Electrical Engineering students and non-majors, findings also highlight challenges in precisely aligning analogies with circuit variables, emphasizing the need for careful implementation and refinement in future studies.

Introduction

Electric Circuits courses are foundational for engineering students, yet many enter with misconceptions and anxiety. Concepts such as voltage, current, and power are often abstract, and students lack prior exposure. These challenges result in low confidence and misconceptions, leading to poor performance [1], [2]. Misunderstandings of foundational concepts such as Kirchhoff's Laws, Ohm's Law, and voltage often persist despite prior coursework in physics or math [3].

The Circuit Teaching with Real-World Analogies (CTRWA) framework was developed to address these issues [4]. CTRWA systematically applies analogies to help students relate circuit concepts to familiar real-world systems, such as comparing voltage to water pressure or using a running track analogy for Kirchhoff's Voltage Law (KVL). This paper evaluates the preliminary effectiveness of CTRWA in improving understanding, addressing misconceptions, and building student confidence.

Methodology

The inventory of Circuit Teaching with Real-World Analogies (CTRWA) was developed by incorporating real-world physical concepts and illustrating them through diagrams in quizzes and tests. These analogies were drawn from engineering practices and included:

1. Voltage and Current: Voltage corresponds to water pressure, and current corresponds to flow rate in a pipe system.
2. Ohm's Law: A narrow pipe restricting water flow represents resistance, where greater restriction limits flow just as higher resistance reduces current.
3. Kirchhoff's Voltage Law (KVL): A running track analogy illustrates energy conservation around a loop.
4. Potential Energy and Voltage: A snowball rolling down a mountain represents voltage potential, as elevation (voltage) drives movement (current).
5. Nodal Analysis: A house plumbing system models node equations, where water distribution among pipes mirrors current division at circuit nodes.
6. Solar Charging Station: Real-world renewable energy applications model electrical components.

Given the diversity of student backgrounds, analogies were selected to resonate with most students while remaining adaptable. The water flow analogy—familiar to nearly all students—proved highly effective, while others, such as the running track analogy, had mixed success and required alternative explanations for students less familiar with sports. While analogies improve comprehension, some mismatches exist between real-world and circuit behavior. For example, while both water flow and current involve movement, electrons do not "flow" as water does; instead, they move under an electric field. Similarly, energy loss in a running track analogy does not perfectly map to voltage drops, which result from resistive components rather than dissipative motion. Future refinements aim to clarify these distinctions while maximizing analogy benefits. Approximately 10% of instructional time is dedicated to analogy-based teaching. Instructors used whiteboard diagrams to connect analogies with circuit principles. For example, in an Ohm's Law lecture, water flow through pipes illustrated resistance. Students discussed these relationships on discussion boards, reinforcing understanding through problem-solving activities. To evaluate CTRWA, quizzes compared students taught with analogies versus traditional methods. One quiz (Figure 1) analyzed water systems representing electrical concepts such as high voltage (high pressure) and resistance (valve restrictions). Surveys showed 83% of students correctly applied analogies, supporting CTRWA's effectiveness while highlighting areas needing refinement.

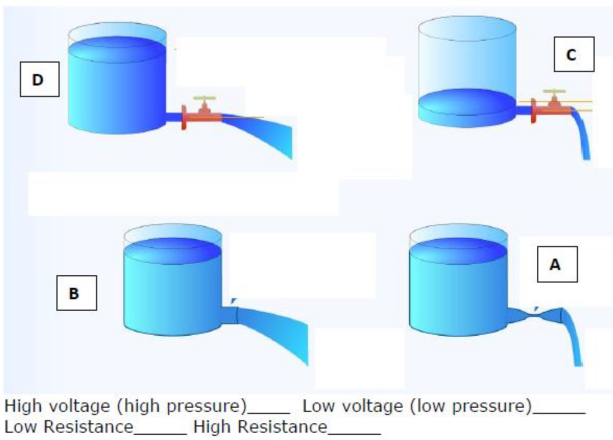

Fig. 1: Quiz Question asking students to match circuit law/concept with water tank operation

Preliminary Observations and Challenges

On the in-person quiz, 50 students were shown three images (a water valve, a water bottle, and a track and field runner) to measure their understanding of electric current. Results showed that 45% chose the track and field runner while 48% selected the water valve image. This suggests that students associate motion-based analogies, like a runner, with current flow, while others relate it more to fluid movement. Another quiz evaluated the voltage potential analogy using an image of a snowball rolling down a hill. Of the 50 responses, 32 students drew incorrect diagrams, indicating a need for better conceptual clarity. A correct analogy represents voltage potential with electric charge moving down a slope and resistance symbols included. This highlights the need to refine explanations to help students better map real-world concepts to circuit principles.

A different quiz asked students to match one of four water tank images to phrases used in circuit analysis. Notably, 83.3% (40 out of 48 students) answered correctly, demonstrating strong understanding. Students who performed well on analogy-based quizzes also reported increased confidence in solving circuit problems. Preliminary findings revealed that students taught with analogies scored an average of 12% higher on quizzes compared to those taught with traditional methods. Additionally, students exposed to analogies were 20% more likely to report increased confidence.

Among the analogies used, the *water-flow analogy proved to be the most effective*, as nearly 80% of students found it helpful for understanding voltage and current. The clear relationship between water pressure and voltage, as well as water flow and current, made it intuitive. However, about 15% of students found the running track analogy less relatable, possibly due to unfamiliarity with sports. These findings suggest the need for alternative analogies that better resonate with diverse student backgrounds.

For the solar charging station analogy, 72% of students matched all terms correctly, although some confusion persisted. For example, 10% mistook 'DC Source' for the interface controller, and 15% confused 'computer controller' with the image of a cell phone. These findings suggest areas for refining analogies, particularly in distinguishing components with similar terminology.

A survey conducted at the end of the semester confirmed that students preferred real-world analogies over AI tools like ChatGPT, highlighting their value in establishing a strong conceptual foundation and boosting confidence. Table 1 presents key survey results at the semester's end.

Table 1: Student Perception of Real World Analogies

Survey Question	Key Results
Like analogy problems?	79.6% of students liked them
Recommend analogies?	76% said 'Yes', 24% 'Maybe', 0% 'No'
Prefer ChatGPT vs. analogies?	76% prefer analogies, 24% prefer ChatGPT
Favorite Analogy	Water-based analogies are most popular.

This table highlights the positive reception of analogy-based learning, with nearly 80% of students preferring analogies over traditional methods or AI tools like ChatGPT. The water-based analogies were the most popular, reinforcing their effectiveness in bridging abstract concepts with real-world understanding. A summary of real-world analogies employed during the Fall 2024 semester is shown in Table 2.

Table 2: Summary of CTRWA Inventory

Circuit Concept	Analogy	Equation/Variable Mapping
Voltage (V)	Water Pressure	V ↔ P (pressure)
Current (I)	Water Flow	I ↔ Flow Rate
Resistance (R)	Narrow Pipe Restricts Flow	$V = IR$; R ↔ Pipe Width
Kirchhoff's Voltage Law (KVL)	Running Track Energy Conservation	$\Sigma V = 0$; Energy loss/lap ↔ Voltage drop
Potential Difference	Runner Jumping Over a Hurdle	ΔV ↔ Height Change
Superposition	Household Plumbing System	Independent water sources ↔ Independent voltage sources

These findings suggest that real-world analogies, such as the water-flow and snowball analogies, effectively address misconceptions about voltage and current, while also increasing students' confidence in applying these concepts. The strong performance of the water-flow analogy reinforces its effectiveness in bridging abstract concepts with real-world understanding, particularly due to its intuitive mapping to pressure and flow relationships in electrical circuits.

Conclusion and Future Work

The overwhelming majority of students enjoy and find value in real-world analogies for learning circuits, especially for foundational concepts like voltage, current, and nodal analysis. This study provides a framework for incorporating analogy-based teaching methods that not only address misconceptions but also foster student engagement and confidence in tackling circuit problems. The potential of CTRWA to improve learning in Electric Circuits is promising.

While most students recommend analogies, a small subset suggests they might not be universally applicable due to individual learning preferences or the analogy's relevance to specific circuit problems.

Next Steps:

- Expand the analogy inventory and pilot CTRWA in multiple courses.
- Conduct controlled studies comparing analogy-based teaching to traditional methods.
- Develop multiple analogies for each concept, allowing instructors to choose examples that resonate best with their student demographics.
- Include follow-up questions or discussions to ensure students correctly interpret the analogies.
- Invite students to suggest their own analogies, fostering a more inclusive and relatable learning environment.
- Measure the effectiveness of analogies for more complex concepts, such as Thevenin equivalents and source-free RC circuits, in relation to students' personal experiences.

Future work will pilot CTRWA in multiple courses to assess its scalability and effectiveness. This includes developing modular analogies for complex topics, providing instructors with a customizable toolkit. Comparative studies across institutions will evaluate the long-term impact of analogy-based learning on student outcomes. Surveys indicate that analogies improve engagement and conceptual understanding, particularly for foundational concepts like voltage and current. Future research will explore optimizing analogy-based instruction within the curriculum to enhance clarity without limiting topic coverage. Feedback from students and faculty will refine CTRWA, preparing students for more advanced circuit analysis. The success of CTRWA depends on collaboration with educators to ensure analogies align with diverse student needs and course objectives. Controlled studies will compare analogy-based teaching with traditional methods to assess student learning gains. We invite ECE instructors to implement CTRWA analogies and provide feedback. Collaborators can suggest new analogies or participate in pilot studies, particularly in advanced courses like Circuit Analysis II and Electronics.

References

[1] A. Espera, N. Pitterson, R. Perez, "Understanding potential misconceptions shared between instructors and students in fundamental electric circuits," ASEE Virtual Conference, Paper ID# 29791, June 2020.

[2] N. Pitterson, N Perova-Mello, R. Streveler, "Engineering Students' Use of Analogies and Metaphors: Implications for Educators," International Journal of Engineering Education Vol. 35, No. 1(A), pp. 2–14, 2019.

[3] N. Hansu, K. Yao, A. Al Weshah, O. Olaogun, S Wang, "Work in Progress: The Electric Circuit Concepts Diagnostic (ECCD)," Paper ID# 36966, ASEE Annual Conference, July 2022.

[4] A. Espera, N. Pitterson, "Exploring Students' Learning of Electric Circuits in Real-world Context," Paper ID# 32602, ASEE Virtual Conference, July 2021.