WIP: Designing Troubleshooting Exercises Across Modalities

Carson Jenkins, University of Virginia

Carson Jenkins graduated from the University of Virginia in 2026 with a degree in Mechanical and Electrical Engineering.

Alexis Alms, University of Virginia
Mr. Kailash Niranjan Patel, University of Virginia

Kailash Patel graduated from the University of Virginia in 2026 with a degree in Electrical Engineering and Music. He is interested in effective instruction of fundamental troubleshooting skills in all engineering disciplines.

Dr. George Prpich, University of Virginia

George Prpich is an Associate Professor of Chemical Engineering at the University of Virginia, where his research focuses on developing methods and tools to assess troubleshooting and problem-solving skills within the engineering curriculum.

Dr. Caroline Crockett, University of Virginia

Caroline Crockett is an assistant professor at the University of Virginia in the Electrical and Computer Engineering department. She received her PhD degree from the University of Michigan in electrical engineering. Her research interests include troubleshooting and conceptual understanding.

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1 Introduction

Troubleshooting is the iterative process of locating the reason for a system malfunction and the subsequent resolution of the fault, often under a time constraint [1], [2]. One common framework reduces the troubleshooting process to five iterative steps: (1) system comprehension, (2) testing, (3) error localization, (4) error rectification, and (5) error evaluation [3]. Within each step, troubleshooting calls for a variety of strategies. Some global troubleshooting strategies include trial and error, topographic search (structurally tracing the system from beginning to end to identify the fault), and split half search (breaking the system down into chunks and testing each sub-system separately) [3]. These global strategies transfer between engineering domains.

A lack of appropriate, effective, and easy-to-use troubleshooting tools currently limits troubleshooting instruction, especially when compared to the wide availability of debugging tools and instruction resources in programming courses [4]. Recent literature [5] explores various methods of teaching troubleshooting in undergraduate engineering courses. However, these approaches are ad hoc and typically target a small population of engineering undergraduates, such as students in a particular major (Michaeli and Romeike [2] is one exception).

Based on a systematic review of the literature, Romeo and Olewnik [5] call for research on cross-disciplinary troubleshooting exercises, research focusing on troubleshooting processes and strategies, grounding of troubleshooting research and instructional design in educational theories, and more detailed data collection for assessing troubleshooting skills. This paper is the first step toward such research: we aim to develop cross-disciplinary troubleshooting exercises that will allow for future research on troubleshooting processes.

When developing the exercises, one design decision was whether to use a hands-on exercise, a paper exercise, or a simulation. In a hands-on activity, students must move things around and immediately observe the impact of their actions. A paper activity challenges students to visualize changes and the possible effects of their actions. A simulation allows users to see consequences but removes the tactile interface. Given the lack of research comparing the modalities, this work-in-progress (WIP) study presents two troubleshooting exercises for a general undergraduate engineering student adaptable to different modalities. We describe our design decisions with the goal of informing the development of additional activities.

2 Literature Review

Previous work, e.g. [6], [7], used think-aloud interviews and observations during hands-on exercises to identify troubleshooting strategies of students in an electronics course and a chemical engineering lab course. Some strategies are specific to the exercises being hands-on. For example, the "directed tinkering" strategy [6] and "tracing strategy " [7] rely on the ability to quickly observe the impact of an action. Meanwhile, Fritz et al. [8] used a custom-built digital format to assess troubleshooting. This method is more scalable and can acquire detailed observation information that an observer may not notice or that a student may not include in a reflection.

We are not aware of any prior literature comparing students' troubleshooting strategies across different modalities. However, there is prior literature on comparing student performance in exams across paper and digital mediums [9], [10], [11]. Studies on digital vs print exams frequently mention that computer-based assessments are detrimental to student performance due to physical limitations such as screen size or keyboard quirks [10], [11], decreased reading speeds in digital formats [11], and a lack of familiarity with technology [9]. Despite these results, many studies claim that an online format is not inherently a problem and call for more user-friendly designs. Many of the studies on exam modalities are on K-12 populations and in non-engineering contexts, so the transferability of the results is uncertain. However, the studies raise relevant themes on student comfort and familiarity with a modality.

3 Method

The aim of the developed troubleshooting exercises is to assess different methods for capturing and teaching troubleshooting. The exercises are inspired by familiar problems or systems to enhance student engagement. Similar to [2], we fashioned exercises that required some system comprehension, but were attainable for all undergraduate engineering students. These exercises had to be short enough to implement within a class period and flexible enough to be offered in different modalities. Finally, we designed the exercises to elicit specific troubleshooting strategies as [6], [7] describe.

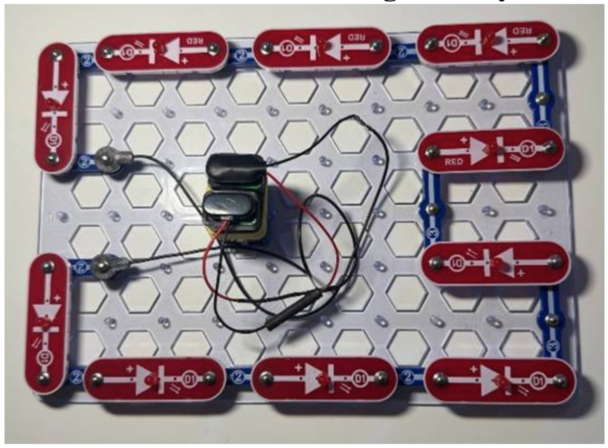
3.1 LED Troubleshooting exercise design

The first exercise was inspired by the daisy chain of USB cables in [2] and by the classical string of holiday lights problem. The objective of the exercise is to determine the fault causing a series of LEDs to remain unlit. Fig. 1 shows the paper version of the exercise. The corresponding hands-on version involves providing the pictured hardware, instructing students that they may make any changes they wish other than undoing the taped battery pack, then giving them a set amount of time to attempt to find and repair the fault.

The design uses Elenco Snap Circuits kits [12], a modular toy meant to teach children basic circuit design. The components are large and easy to connect; they snap to each other and anchor to a peg-filled board for stability. We selected these components to make the exercise durable, user-friendly, and approachable for participants with little circuit design experience. The LEDs are in an approximate circle, aiding in systematic comprehension of the system when troubleshooting.

To adapt the existing kit for our purposes, we required a higher voltage power source than the 3 V battery packs offered by the product kits. The LED's forward voltage is 1.5 V [12], so the circuit requires two 9 V batteries to power all LEDs. We added an additional 680-ohm resistor to protect the circuit from overcurrent if students short the battery. The overcurrent protection resistor is soldered then concealed in shrink wrap tubing in between the 9 V battery connections to prevent participants from removing it from the circuit.

LED Troubleshooting Activity



The photo above shows ten LEDs in a series circuit. The LEDs are supposed to be lit, but they are not. The LEDs and wires are all modular and snap together. You may freely move around the components on the board. For example, you may disconnect each LED and reconnect the circuit with some subset of the LEDs instead of all ten. Assume the circuit has an adequate power supply, so the battery pack in the center of the board is not an issue and should not be touched.

Write up to five actions you would take to understand why the LEDs are not lit. List your steps sequentially: assume the previous step you listed was not successful, which prompted you to try something else.

Figure 1: LED exercise paper version. When functioning, current flows from the red (positive) battery wire into the Snap Circuit components and through each LED to the black battery wire

There are different possible faults for the same set-up depending on a student's background knowledge, desired difficulty level, and desired troubleshooting strategies:

- Broken LED: String lights are wired such that one broken bulb extinguishes the whole strand. To introduce this fault, we subtly "broke" an LED by prying apart the plastic housing of a Snap Circuits LED and snipping the wiring inside to render the LED useless. This fault encourages a split-half or topographic troubleshooting strategy. Split-half consists of testing subsets of LEDs at a time to see which work.
- Flipping LEDs: LEDs are polarized and must be oriented correctly for current to pass through them. A few or all LEDs may be flipped the wrong way. Troubleshooting would require system comprehension or trial and error.
- Insufficient voltage source: A single 9V battery or two drained 9V batteries are insufficient to light all LEDs in series. Students may replace the battery pack or wire the LEDs in parallel. This was designed to focus on system comprehension and the realm of possibility.

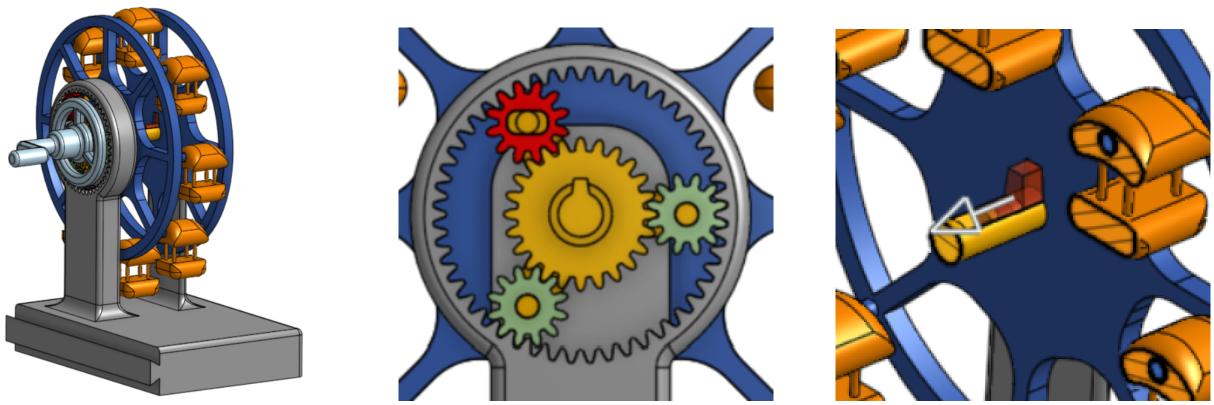
For a more advanced troubleshooting exercise, instructors can combine multiple faults.

4 Ferris Wheel Troubleshooting Exercise Design

This exercise incorporates motion and requires more mechanically-oriented system comprehension. Similar to the LED design, the Ferris wheel is a system that students are familiar with. The objective of this exercise is to determine the fault in a Ferris wheel.

We initially tested a wooden Ferris wheel building kit with an electric motor. The kit was to build your own Ferris wheel, making it easy to make design changes. To incorporate a troubleshooting element, we swapped the location of the drive shaft gear and a space such that the gear teeth were too far apart to spin the wheel. However, the product was not sturdy nor durable and we frequently had a broken Ferris wheel work by pushing on the wheel to engage the poorly aligned gears.

The updated Ferris wheel design replaces the electric motor and battery system with a fully mechanical system, driven by a removable hand crank. The custom CAD-designed model emphasizes mechanical power transmission and structural behavior. The design improves structural integrity and handling durability by using 3D-printed components in place of glued wooden parts and allows for further customization.



(a) Updated Ferris wheel design with a planetary gear and shaft failure mode.

(b) Planetary gear train with the locking planetary gear in red at the top.

(c) A section view of the sliding shaft key engaged with both the Ferris wheel hub and stand.

Figure 2: Custom Ferris wheel design.

The design features a planetary gear train, with a hand crank attached to the central sun gear. Rotation of the sun gear drives the surrounding planet gears within the carrier, ultimately rotating the Ferris wheel axle. The Ferris wheel features two main failure modes:

- Locked Planetary Gear (Fig. 2b): The red (top) planetary gear has an elliptical bore (central hole). The non-circular design prevents rotation on the shaft. When included in the gear train, the gear locks the assembly. Removing the gear allows the handle to rotate freely.
- Sliding Shaft Key (Fig. 2c): The red sliding key on the shaft can lead to two distinct failure modes. If positioned too close to the handle, it does not engage the Ferris wheel hub, preventing torque transfer to the axle. As a result, the handle can rotate without driving the wheel. If positioned too far from the handle, it also engages the Ferris wheel stand in addition to the wheel hub, locking both the handle and wheel and preventing rotation.

Both faults were designed to focus on willingness to disassemble the system, system comprehension, and directed tinkering. Additionally, the design has a dovetail interface, so it can be easily expanded upon to include more complex failures. As with the LED exercise, instructors may combine faults for a more challenging troubleshooting scenario.

When working with the wooden Ferris wheel, we tested a version that presented a 360 video with motor sounds audible. Similar to the LED design, this online version includes a form prompting students to write down steps they would take to resolve the fault. For the custom Ferris wheel, a single video cannot capture all of the pieces without giving away too much information by removing certain components. Instead, we plan to make an interactive simulation that allows the user to specify which pieces of the Ferris wheel to move and displays the results.

5 Conclusion

Hands-on troubleshooting activities provide students with a authentic troubleshooting experiences and our experience is that most students are excited to engage with the troubleshooting activities. Designing hands-on activities that engage students across engineering disciplines, target specific troubleshooting strategies, and are easy to implement in class can be challenging. Development can be resource-intensive while execution might require multiple units, specialized equipment, or complex logistical coordination. While paper-based or simulation exercises do not provide physical interaction, they reduce logistical constraints and increase scalability.

We have developed exercises that can be offered in at least two modalities each. These exercises can help explore the impact of modality on student troubleshooting approach. As this work continues, we will examine student troubleshooting performance across these different instructional modalities to identify which approaches are most effective in specific contexts. A significant challenge is how to best collect the assessment data; our next steps involve comparing data from think-aloud interviews, self-reflections, peer observations, and observations by a trained observer. These results will inform best practices for assessing and teaching troubleshooting.

References

[1] N. M. Morris and W. B. Rouse, "Review and evaluation of empirical research in troubleshooting," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 27, no. 5, pp. 503–530, Oct. 1985. DOI: 10.1177/001872088502700502.

[2] T. Michaeli and R. Romeike, "Investigating students' preexisting debugging traits: A real world escape room study," in *Koli Calling '20: Proceedings of the 20th Koli Calling International Conference on Computing Education Research*, Koli Finland: ACM, Nov. 19, 2020, pp. 1–10, ISBN: 978-1-4503-8921-1. DOI: 10.1145/3428029.3428044.

[3] D. H. Jonassen and W. Hung, "Learning to troubleshoot: A new theory-based design architecture," *Educational Psychology Review*, vol. 18, no. 1, pp. 77–114, Mar. 2006. DOI: 10.1007/s10648-006-9001-8.

[4] S. Yang, M. Baird, E. O'Rourke, K. Brennan, and B. Schneider, "Decoding debugging instruction: A systematic literature review of debugging interventions," *ACM Transactions on Computing Education*, vol. 24, no. 4, pp. 1–44, Dec. 31, 2024. DOI: 10.1145/3690652.
[5] C. Romeo and A. Olewnik, "Troubleshooting in engineering education: A systematic literature review," in *2025 ASEE Annual Conference & Exposition Proceedings*, Montreal, Quebec, Canada: ASEE Conferences, Jun. 2025, p. 57 722. DOI: 10.18260/1-2--57722.
[6] M. Kinsel, C. Crockett, N. Smith, and G. Prpich, "Circuit troubleshooting techniques in an electrical and computer engineering laboratory," in *2024 ASEE Annual Conference & Exposition Proceedings*, Portland, Oregon: ASEE Conferences, Jun. 2024, p. 48 461. DOI: 10.18260/1-2--48461.
[7] G. Prpich, N. Smith, C. Crockett, and A. Shrestha, "Building better engineers: Teaching chemical engineers to troubleshoot in the laboratory," in *2024 ASEE Annual Conference & Exposition Proceedings*, Portland, Oregon: ASEE Conferences, Jun. 2024, p. 48 424. DOI: 10.18260/1-2--48424.
[8] A. Fritz, M. Horowitz, and A. Jha, "Online, interactive tool for studying how students troubleshoot circuits," in *2021 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual Conference: ASEE Conferences, Jul. 2021, p. 37 542. DOI: 10.18260/1-2--37542.
[9] M. B. Scrimgeour and H. H. Huang, "A comparison of paper-based and computer-based formats for assessing student achievement," *Mid-Western Educational Researcher*, vol. 34, no. 1, pp. 69–92, 2022. [Online]. Available: https://eric.ed.gov/?id=EJ1336937.
[10] N. Dadey, S. Lyons, and C. DePascale, "The comparability of scores from different digital devices: A literature review and synthesis with recommendations for practice," *Applied Measurement in Education*, vol. 31, no. 1, pp. 30–50, Jan. 2, 2018. DOI: 10.1080/08957347.2017.1391262.
[11] J. M. Noyes and K. J. Garland, "Computer- vs. paper-based tasks: Are they equivalent?" *Ergonomics*, vol. 51, no. 9, pp. 1352–1375, Sep. 2008. DOI: 10.1080/00140130802170387.
[12] *SCL-175 paper manual*, 2021. [Online]. Available: https://www.elenco.com/wp-content/uploads/2021/12/SCL-175_Paper-Manual_V1_2021.pdf.