Welcome to the UL Xplorlabs: The Science of Thermal Runaway, Engineering Solutions

Underwriters Laboratories' (UL) Science of Thermal Runaway module provides opportunity for students to make sense of the science related to lithium-ion battery-powered devices; and then consider real battery failure testing data in order to engineer solutions associated with the phenomena of thermal runaway. This UL module is framed most like a PBL with explicit teaching and learning of all three dimensions in science and engineering. Details of this design are outlined in Table 1: Next Generation Science Standards (citation). An overview of the instructional flow follows.

Engineering Design Challenge

Through the suggested pathway, engineering a solution to a safe battery enclosure is at the core of student motivation to engage in sense making of the science. Challenges associated with safe battery enclosures are defined early in the module, with subsequent learning cycles designed for students to make ongoing connections to the problem definition. As students make their thinking visible through models, discussion, and ideation of possible solutions they will consider the following:

- Materials for a battery enclosure
- Optimization of an enclosure design

See the teacher guide for the Engineering Process: Designing a Lithium-Ion Battery Enclosure for details.

Suggested Pathways

We have created a set of pathways that aligns closely with NGSS (citation) (see Table 1). It is important to note that the suggested instructional sequences, are a vision for how instruction could occur, not a prescription nor recipe from a cookbook. To be fair, there is no singular way to approach phenomena driven problem-based learning cycles. Thus, we encourage you to try as much or as little for what makes the most sense for appropriately challenging your students.

The suggested pathway begins with a shared experience and/or acknowledgement that the world we live in is dependent upon portable electric power, specifically lithium-ion batteries. Students question and conceptualize challenges of lithium-ion batteries (e.g., lighter, cost effective, power, size). Then, as students' progress through the learning cycle(s), they explore driving questions that they can later explain through engineered solutions to specific problems (e.g. battery enclosures, safety labels).

- Introduction to Thermal Runaway
  Students record observations from lab tests conducted at the UL Electrochemical Safety Research Institute and then share their wonderings about a lithium-ion battery powered device that is on fire. These wonderings, become driving questions that serve as a guide to the remainder of the learning cycle.

Engage A lithium-ion battery powered device is on fire.	**Explore Questions** Students share related questions that quide learning.	**Connect to Engineering Design Challenge** Students identify the problem: to construct battery enclosures that mitigate hazards that cause thermal runaway.

- How does a lithium-ion battery work?
  Students observe energy transformations that occur as a result of lithium-ion batteries, paying particular attention to the byproduct of thermal energy that results. Specifically, students use either real on online animations of lithium-ion batteries to complete circuits that support direct observations of transformations of energy and then explain how lithium-ion batteries transform energy.

Explore Energy Transformations A lithium-ion battery powered device is on fire.	**Explore Energy Transformations** Students explain energy transformations that occurr with lithium-ion batteries.	**Connect to Engineering Design Challenge** Students identify the challenge for engineers to construct battery enclosures that mitigate the byproducts of thermal energy.

- How is overcharge connected to thermal runaway?
  The safety of a battery depends on how it is recharged. Therefore, for this portion of the learning cycle, students explore the effects of overcharging using a virtual simulation of mismatched chargers, a common misuse among consumers. Through this driving question students will be able to explain that overcharging can create an uncontrolled chain reaction of heat, or thermal runaway.

Explore Students observe the effects of overcharging via online simulation.	**Explain** Students explain cause and effect in terms of how overcharging can contribute to thermal runaway.	**Connect to Engineering Design Challenge** Students identify the need for correct chargers and safe charging practices. They consider how design could contribute to safe charging.

- Why do battery powered devices need to be designed to minimize damage?
  Students watch video examples of how safety engineers construct conditions to test batteries to the point of failure. Then, students carry out a digitally simulated investigation to see how dropping a device impacts the likelihood of thermal runaway. Through this driving question students will be able to explain how damage can lead to the internal short circuits that cause thermal runaway.

Engage	Explore	Explain	Connect to Engineer Design Challenge
Observe the effects of crushing and puncturing on a battery with ULRI Lab footage.	Plan and carry out an investigation to measure the ffects of droppinng a hoverboard in a virtual lab.	Students explain cause and effect in terms of how damage can contribute to thermal runaway.	Students improve upon their description of how engineers design enclosures to consider damage and strength.

- How does thermal runaway spread?
  Students will view real UL Lab Experiments that place batteries in extreme heat to observe the likelihood they will release high pressure gas and become airborne. Through this driving question students will understand how build-up of gas inside the confined volume of the battery can lead to spread of fire, as well as how excessive heat of one battery in thermal runaway can spread to other cells.

Explore	Explain	Connect to Engineering Design Challenge
Observe the effects of crushing and puncturing on a battery with ULRI Lab footage.	Students explain thermal energy transfer and its effects on thermal runaway in other cells, as well as to the device and its surrounding environment.	Students finalize their defination of the problem. Students identify potential risks due to thermal energy transfer.