UL XPLORLABS

PORTABLE ELECTRICAL POWER

EDUCATOR

TEACHER OVERVIEW OF THE MODULE

CASE STUDY OF SCIENCE AND ENGINEERING

SCIENTISTS ASK WHY. ENGINEERS ASK HOW.

AGE GROUP
Middle School

CATEGORY
Physical Science

COMPLETION TIME
1 - 3 Class Periods

WHAT IS ENGINEERING IN SAFETY SCIENCE?
HOW DO ENGINEERS DESIGN OUR WORLD TO BE A SAFER PLACE?

This module is designed to provide students with the understanding of the extensive use of lithium-ion batteries in our daily school and home lives, along with the risks and challenges posed by the widespread use of these batteries, so that they can develop new designs based on the constraints of these challenges.

The videos and interactive investigations within the module bring students into the UL Battery Lab to engage in testing the limits of batteries in ways that are otherwise unsafe and not feasible to do in a classroom, school, home, or after-school, etc. setting.

Classroom investigations, including detailed teacher guides and student pages, provide opportunities to deepen student understandings through hands-on experiences that allow students the opportunity to engage in the design/redesign process of safety engineering, based on The National Research Council's Science and Engineering Practices (see below). These investigations afford students the opportunity to design/test/redesign battery enclosures for a hoverboard that protect both the battery and the person using the hoverboard.

The following guide serves an overview of each section for you, the educator, to provide a road map of the module and supporting content from the UL Battery Lab.

NEXT GENERATION SCIENCE STANDARDS ALIGNMENT

PORTABLE ELECTRICAL POWER SUPPORTS PERFORMANCE OF THE FOLLOWING NGSS MIDDLE SCHOOL IN PHYSICAL SCIENCE*:

MS-PS3: Energy. Students who demonstrate understanding can:
- Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object. (MS-PS3-1).
- Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. (MS-PS3-3)
- Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

The related Disciplinary Core Ideas (DCIs)(NOT DCI's) addressed in this module include:
- Definitions of energy (PS3.A)
- Conservation of energy and energy transfer (PS3.B)
- Relationship between energy and forces (PS3.C)

MS-ETS1:
Engineering Design. Students who demonstrate understanding can:
- Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions (MS-ETS1-1).
- Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. (MS-ETS1-2).
- Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. (MS-ETS1-3).
- Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. (MS-ETS1-4).

The DCIs addressed in this module include:
- Defining and Delimiting Engineering Problems (ETS1.A)
- Developing Possible Solutions (ETS1.B)
- Optimizing the Design Solution (ETS1.C)

Portable Electrical Power contributes to student understandings of the Science and Engineering Practices including:
- Planning and Carrying Out Investigations
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence

*Achievement of these benchmarks based on completion of entire module.

The module addresses and reinforces the cross-cutting concepts of cause and effect, scale, structure and function, systems and system models. Performance expectations for students include engaging in analyzing and interpreting data, argument from evidence, and use of these practices to demonstrate understandings of core ideas in PS1 and PS3.

These assessments are built into the main module and are included in the "evaluate" section of each classroom investigation.

ENGINEERING AND DESIGN PROCESS

From cell phones to laptops and electric cars to hoverboards, portable electrical power and lithium-ion batteries are part of students' lives every day. They are also the result of scientific inquiry and engineering.

This UL Xplorlabs module encourages students to use scientific inquiry to engage with portable electrical power, teaching them how batteries convert energy, introducing the phenomenon of thermal runaway, and inspiring them to think like a scientist to identify essential construction and performance requirements that address the inherent risks a product could present. Students will develop useable knowledge to explain real-world phenomena by learning how to define a problem, build a solution, test a design, then analyze and extend results.

The National Research Council (NRC) defined the practices, skills, and thinking necessary in science and engineering learning for students. Portable Electrical Power is built on these practices, specifically:

- defining the problem and challenges posed by the wide-spread use of lithium-ion batteries,
- investigating the safety of products using lithium-ion batteries in the laboratory,
- analyzing and interpreting data from these tests,
- constructing explanations and designing solutions in the classroom investigations, digging into safe product design, and
- communicating information to peers, families, and schools about the safe use of lithium-ion batteries.

WELCOME TO THE UL BATTERY LAB!

A friend just got a cool new hoverboard, but you just read a story about hoverboards being dangerous and a fire risk. You want to be excited for your friend, but also want your friend to be safe.

Your students' job will be to design a safer hoverboard, but first they need to learn about lithium-ion batteries and the phenomenon of thermal runaway. Portable Electrical Power will take your students through UL's battery lab where batteries are pushed to the extreme so that manufacturers know what their limits are and how to keep people safe in a world full of portable devices powered by lithium-ion batteries.

THE PORTABLE ELECTRICAL POWER IS A SERIES OF VIDEOS AND INTERACTIONS. THE ORDER AND EXPLANATION OF THE MODULE PARTS ARE LISTED BELOW.

I. INTERACTIVE VIDEO.

The interactive video is an engaging exploration of portable electrical power and the phenomenon of thermal runaway. The video builds content knowledge about the lithium-ion battery, explains thermal runaway, and includes lithium-ion battery testing demonstrations.

Below, each section of the interactive video is summarized with definitions and key takeaways.
This content is also included in each section on screen.

The interactive video explores:

1. Inside a lithium-ion battery. What makes up the basic anatomy including the anode, lithiated carbon, electrolyte, separator, cathode, and lithium metal oxide.

   Key Takeaway – A lithium-ion battery is an energy storage device in which lithium-ions move from the cathode to the anode, kept apart by a separator. The movement of these ions produces heat.

2. Thermal runaway. The phenomenon causing the greatest risk in lithium-ion batteries, and how it occurs.

   Key Takeaway – Thermal runaway happens when the separator between the anode and cathode breaks down causing the chemicals in the battery to mix and generate more and more heat leading to popping, burning, and in some cases, explosions.

3. Xtreme Xperiments. We know how thermal runaway occurs because of safety tests conducted in the UL Battery Lab that push lithium-ion batteries to their limits. These tests are done in a very controlled lab setting to understand the consequences of misuse and the effects of faults or failures within the batteries. This section gives students an opportunity to understand how and why the batteries are tested in a safe way. We cannot emphasize this enough – do not try this at home or at school! Classroom investigations are designed for students to have safe classroom experiences.

   - CRUSH TEST – what happens to a lithium-ion battery when it is put under extreme force?
   - BLUNTED NAIL TEST – what happens when a lithium-ion battery is punctured?
   - PROJECTILE TEST – when a lithium-ion battery is over-heated and explodes, will it penetrate a metal screen? Will the battery spread fire on a large scale?
   - ABUSIVE OVERCHARGE TEST – will the protections engineered inside the battery keep the lithium-ion battery from overcharging, overheating, and going into thermal runaway?

   Key Takeaways – Safety engineers push batteries to the extremes based on how a battery might be used or misused and what happens when a fault or failure happens inside the battery.

II. XTREME TESTING: INTERACTIVE EXPERIENCE

A simulated set of tests that put your students in the role of safety scientist, dropping and overcharging a hoverboard under various conditions to evaluate how well it holds up to the stresses and abuses of everyday life.

- THE XTREME DROP TEST – students drop the hoverboard from heights up to eleven feet; inspect the hoverboard for damage, then run the hoverboard to test for faults or failures as a result of the drop.
- THE XTREME OVERCHARGE TEST – students choose a charger for the hoverboard, and then test the effects of the charger from the internal heat.

Key Takeaways – Because of safety engineering we can have many devices that require lithium-ion batteries. The Drop Test and Overcharge Test are two ways safety engineers test for product safety.

III. HANDS-ON CLASSROOM EXPERIMENTS (CLASSROOM INVESTIGATIONS)

The investigations provide the students with an opportunity to think through the materials used in protecting a lithium-ion battery in a hoverboard, while protecting the user at the same time. Students investigate a single cell battery and its risks and hazards, then evaluate materials according to the UL Safety Standards process to build a safe, durable hoverboard. Each experiment can stand alone, but we recommend completing all three.

Investigations also include a teacher guide with procedures and relevant background information and student pages including tables to gather data where appropriate.

All investigations are developed to give students practice in safety engineering design and the design/redesign process.

All investigations are correlated to the Next Generation Science Standards middle school benchmarks in physical science. See the teacher's guide for each investigation for specific alignment to NGSS.

Most investigations can be completed in 1-3 classroom periods depending on the length of class time and depth to which you explore the tests with your students.

INVESTIGATIONS:

1. The Bologna Test: In small groups, students will place a piece of bologna on a noncombustible surface. They will place one dropper full of saline in the center of the meat slice, then place a button cell lithium-ion battery in the pool of saline on the bologna. Using a timer, they will observe what happens each minute for 10 minutes.

HOVERBOARD DESIGN CHALLENGE

2. Tensile Test and Durability: Discover which materials have what it takes to protect a battery pack from the outside world and the outside world from the battery pack's heat. What types of testing do safety engineers put materials through? One type of testing is tensile performance – the resistance of a material to breaking under tension. But it's not just the strength of the material that matters, the design is also important. The design of the shape needs to protect the battery pack (and other components, but for this lab, we'll focus on the batteries) and keep the unavoidable battery pack heat from harming the user. Will the design shape stand up to the can of soup (represents the relative weight of a hoverboard passenger)?

3. Thermal test: Conduct thermal testing of your battery pack enclosure that keeps the battery and the hoverboard cool enough to avoid risk of thermal runaway. In this Investigation student groups will use their hoverboard enclosure with the battery pack installed as it was designed in Investigation 2 to determine if the heat transmission through the enclosure, as well as the heat generated inside the enclosure, meet safety standard requirements for thermal performance.

INVESTIGATIONS 2 AND 3 ARE ACCOMPANIED BY A DECISION TREE. THIS KEY WILL HELP STUDENTS IN TWO WAYS:

1. To understand if a design passes;
2. To see that when a design does not pass, it leads to a redesign opportunity.
   The Decision Tree includes the tensile test, durability test, and thermal test.

The results of the design can be carried through to the Classroom Challenge, or the Classroom Challenge can be done without the Classroom Investigations.

IV. XTEND THE LEARNING: CLASSROOM CHALLENGES

UL Xplorlabs challenges students to:

- Sell it! Design and sell a personal transportation device to the world! Communicate the safety benefits of your design in a video, poster, or radio ad,

OR

- Tell it! Design a hoverboard safety Public Service Announcement (PSA) for the world! Make a public service announcement about how to care for products with lithium-ion batteries.

SELL IT!

What's the next big thing in personal transportation? Encourage your class to imagine a new way to travel, and have them write and design promotional ads introducing this new means of travel to the world. The challenge is to come up with an advertising campaign that would emphasize the safety engineering that went into designing the new product and create ads aimed at kids and parents to share.

- Sketch a new design for personal transportation device
- Develop a new name for your device
- List three safety engineering innovations you included in your design
- Develop an ad campaign to market and sell your product
- Create a print ad or social media promotion (don't forget your hashtags)
- Develop a :30 commercial to sell your creation to the world
- Share it with us! Your video could be featured on the Xplorlabs website!

TELL IT!

Many manufacturers are now creating hoverboards that pass mechanical, environmental, and electrical tests, but that doesn't mean kids will use safe behaviors all the time. Kids are riding hoverboards on streets and sidewalks that weren't designed for them. In fact, few places have guidelines on safe usage. That's where you come in! Design a Public Service campaign that highlights the safe use of hoverboards in cities around the world.

- Research hoverboard safety rules in a specific city or country (for a real challenge, choose one that's not your own)
- Come up with rules / standards for safe hoverboard use, or complement existing ones
- Develop a public service campaign to share those rules / standards with kids and parents
- Create a magazine ad that talks about safe hoverboard use
- Develop a :30 public service announcement (PSA)
- Share it with us! Your video could be featured on the Xplorlabs website!

SAFETY IN THE UL LABS.

The tests shown in the Portable Electrical Power module are done carefully in the Battery Lab at UL's campus in Northbrook, IL. The Battery Lab is specially constructed to test the limits of all types of batteries including lithium-ion batteries. These tests are NOT safe for classrooms, schools, homes, or ANY setting outside of a strictly controlled testing environment.

UL Xplorlabs brings these extreme tests to students and teachers through the Portable Electrical Power module.

INVESTIGATIONS

		HOVERBOARD DESIGN CHALLENGE		
At A Glance	**Investigation 1** The Bologna Test	**Investigation 2** Tensile Test and Durability	**Investigation 3** Thermal Test	**Challenge**
Grade Level **Time Required** (Duration based on 60-min periods)	Middle School (6/7/8) Engage/Xplor: 1 class period Xplain/Elaborate/Evaluate: 1 class period	Middle School (6/7/8) **A:** Engage/Xplor: 1 class period Xplor/Xplain: 1 class period Elaborate/Evaluate: 1 class period **B:** Xplor/Design/Build: up to 2 class periods	Middle School (6/7/8) Engage: 1 class period Xplor/Xplain: 1 class period Elaborate/Evaluate: 1 class period	Middle School (6/7/8) 1-4 class periods
Group Size and Roles (see ROLES document)	3-5 students Materials manager, Technician, Spokesperson	3-4 students Materials manager, Technician, Spokesperson, Document controller	3-4 students (keep in same groups) Materials manager, Technician, Spokesperson, Document controller	3-4 students (keep in same groups) Materials manager, Technician, Spokesperson, Document controller
Xploration	**Question to Xplore** – How do safety scientists and engineers solve problems? Can we see the energy in a single button cell battery? Safety scientists ask why a phenomenon happens. Safety engineers ask how they can solve the problem and keep people safe. Both ask how they can design and communicate solutions. The button cell battery is a case study in science and engineering for safety.	**Question to Xplore** – What is the most durable material to use for an enclosure? Safety scientists understand the problem of hoverboards to be related to thermal runaway. As we saw in the XplorLabs investigation of thermal runaway, when a lithium-ion battery is punctured, crushed, overcharged or overheated, or a short-circuit is caused in other ways (like dropping the hoverboard), there is a greater risk of overheating and fire. Safety engineers ask how they can solve the problem and keep people safe. Enclosures help to enclose things for the protection of the internal components and keep people from the hazards inside the product. Even though the enclosure provides the physical protection for components inside a product like the battery pack, it's also very important that it doesn't trap too much heat, creating a situation where a person could burn themselves when they touch it, or ride it, like a hoverboard! In the case of the hoverboards, the challenge is to select a material with the best performance in durability (tensile strength) and heat (thermal performance) that protects the battery pack from the outside world, and protects the user from the battery pack's heat.	**Question to Xplore** – Can a hoverboard enclosure protect the battery pack (durability) and protect the user from the heat produced by the battery pack (thermal performance)? In XplorLabs, engineers follow a set of standards that determine the order and testing a product must go through, be exposed to, and pass to be certified for safety. There are multiple tests required to pass a product design. So, even though the enclosure provides the physical protection for components inside the hoverboard (like the battery pack), it's also very important that the enclosure doesn't trap too much heat, creating a situation where a person could burn themselves when they use it. There are trade-offs in the engineering design process. In the case of the hoverboards, the challenge is to select a material with the best performance in durability (tensile strength) and heat (thermal performance) that protects the battery pack from the outside world, and protects the user from the battery pack's heat.	**Think you have the best design?** Sell it! Communicate the safety benefits of your design in a video, poster, or radio ad. **Want to tell the safety story?** Tell it! Make a public service announcement about how to care for products with lithium-ion batteries.

INVESTIGATIONS

		HOVERBOARD DESIGN CHALLENGE		
At A Glance	**Investigation 1** The Bologna Test	**Investigation 2** Tensile Test and Durability	**Investigation 3** Thermal Test	**Challenge**
Problem to be Solved	*"Electronic devices are a part of daily life. And they're getting smaller, slimmer, and sleeker. But inside the battery compartment of mini remote controls, small calculators, watches, remote keyless entry, flameless candles, singing greeting cards, and other electronics, may be a very powerful coin-sized button battery. When swallowed, these batteries can get stuck in the throat and cause severe burns. Small children often have easy access to these devices, and many parents do not know there is a risk." (http://thebatterycontrolled.com.au, September, 2016).*	Safety scientists explain the problem of thermal runaway. Engineers create ways to solve the problem! Hoverboards need to be made of material that protects the battery, protects us from the heat from the battery pack, and is stable enough for someone to stand on it and handle it in normal and abusive ways (i.e., tossed in a backpack, dropped on accident...hey, it happens!). What types of testing do safety engineers put materials through? One type of testing is tensile performance – the resistance of a material to breaking under tension. But it's not just the strength of the material that matters, the design is also important. The enclosure shape needs to protect the battery pack (and other components, but for this lab, we'll focus on the batteries) and keep the unavoidable battery pack heat from harming the user. Does the design stand up to the can of soup that represents the relative weight of a hoverboard passenger?	Now that the hoverboard enclosure will hold the weight and has the durability to stand up to daily use, does it keep the battery safe while at the same time not overheating internally or overheating the parts that are handled by the user? If not, what changes/modifications can be made to the design?	
Summary of Lab	In small groups, students will place a piece of bologna on a non-combustible surface. They will place one dropper full of saline in the center of the meat slice, then place a button cell lithium-ion battery in the pool of saline on the bologna. Using a timer, they will observe what happens each minute for 10 minutes.	**Part A**: Students will test the mechanical strength (durability) of four materials using a tensile test – can the material hold more than one pound for two minutes without sagging, ripping, tearing, stretching, or showing other types of damage? If the material shows signs of wear or damage, students will have the opportunity to change the composition of the material by adding more layers, etc., to retest the material with modifications (redesign). **Part B:** Students will use the class data from the tensile test to select a material to build the enclosure for the hoverboard meeting a certain set of criteria – the enclosure must be 8"x3"x3" and hold more than one pound for two minutes without damage. Other materials may be used to support the structural integrity of the enclosure. (Option: to include criteria for weight).	Using a bundle of 4 handwarmers that represent the battery pack, students will test the thermal performance of their hoverboard enclosure designs. The final design must protect the battery, support the weight of one pound, keep the internal heat of the battery from rising more than 5°F, and the external temperature of the enclosure from rising more than 7°F.	

INVESTIGATIONS

		HOVERBOARD DESIGN CHALLENGE		
At A Glance	**Investigation 1** The Bolonga Test	**Investigation 2** Tensile Test and Durability	**Investigation 3** Thermal Test	**Challenge**
Outcome - Students will do...	Ask questions and define problems Define engineering problems to be solved Observe phenomenon Construct, use, and present arguments based on evidence Work in cooperative groups	Ask questions and define problems Develop and construct a model to generate data and test ideas Analyze and interpret data and construct graphical displays of data Evaluate competing design solutions based on jointly developed and agreed-upon design criteria Apply scientific ideas or principles to design Construct, use, and present arguments based on evidence Work in cooperative groups		Construct, use, and present arguments based on evidence Work in cooperative groups

ROLES (REMEMBER TO ROTATE!)

THE STUFF SUPERVISOR

- Gathers necessary materials for lab when it is time
- Ensures group has everything to begin investigation
- Ensures materials are used properly and safely
- Sets time and manages stopwatch
- Helps with time management
- Puts materials away when group is finished

THE EXPERIMENT EXEC

- Sets up investigation with material
- Ensures safe and precise use of lab equipment
- Ensures all members of the group participate in investigation
- Takes down investigation when it is time
- Helps clean up

THE PRINCIPAL PRESENTER

- Communicates group questions with teacher or other groups
- Ensures all group members give ideas before asking for help
- Ensures everyone in group agrees on question to ask
- Presents findings/reasoning to the class
- Helps clean up

THE DIRECTOR OF DOCUMENTS

- Ensures proper procedure is being followed
- Ensures data is being collected in proper places (all members record data)
- Helps all voices in group be heard
- Provides positive and helpful feedback to the group
- Helps clean up

XPLORLABS: INVESTIGATIONS PROCESS